Intelligent Controller for 7-DOF Manipulator Based upon Virtual Reality Model

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***Abstract*—A robot is an option to improve productivity in industrial automation. Automated manipulators have been applied to hazardous environments and routine manufacturing functions. Because automated manipulators are nonlinear dynamic systems with a high degree of uncertainty, it is difficult to obtain precise dynamic equations to design control laws. VR is an important part of applications in industrial, medicine, statistics, and other areas where 3D object can help understand complex systems. In this application, interaction with the virtual system can be enhanced by a sense of touch, and rapid feedback can be used to apply representative forces from the virtual environment to a human user.**

The ANFIS approach has become one of the main areas of interest because it gains the benefits of neural networks (NN) as well as mysterious logic systems and eliminates individual defects by combining them with common features. The artificial neural network (ANN) has injected new momentum into the mysterious literature. ANN can be used as a universal learning model for any smooth parameter models, including the mysterious inference system. The mixed learning base used to combine the gradient ratios technique and the Least Square Estimator (LSE) to train the ANFIS network for a particular problem. This chapter introduces the design of the ANFIS for the 7-DOF manipulator model built by the VR environment and simulates this model by connecting Matlab / Simulink with VR to execute commands produced by the system-based ANFIS console. Satisfactory results are obtained in simulations which improve the design as a basic application of this control design.

Keywords*— *Adaptive Neuro-Fuzzy Inference System (ANFIS), 7-DOF Manipulator, Virtual Reality (VR), Artificial Neural Network (ANN).

I. Introduction

Artificial Neural Networks (ANNs) and Fuzzy Logic (FL) are successfully implemented in many difficult robotic applications. However, each of these two smart technologies has its own disadvantages that limit its usefulness to some, not some, attitudes [1,2]. To overcome these deficiencies, the integration of FL and ANN into a unified system has received considerable attention in the literature, resulting in the emergence of a rapidly emerging field of mysterious neurotransmitters. ANFIS is one of the most commonly used neural systems, proposed by [3, 4].

The mixed learning rule, which combines a step-by-step technique with a lower LSE, was proposed in [5,6] to train ANFIS on a particular problem. As a supervised learning method, this mixed learning base requires a learning signal in its work. However, in designing a control system, when using the ANFIS network as a feedback controller, it is difficult to provide this teaching signal, because the required control measures, which represent the teaching signal in this case, are simply unknown [7,8]. In order to alleviate this difficulty, many ANFIS learning methods were proposed in the literature to apply ANFIS as a MIMO controller. For example, Djukanovic et al. [9,10] The special ANFIS learning technique, called backflow (TBP), was used to control nonlinear MIMO systems by looking at both the control unit and the unit as a unit at each time step [11]. However, this method is characterized by extreme calculation and complexity in implementation [12,13].

VR has become an important part of applications in engineering, medicine, statistics and other areas where 3D images can help understand complex systems. In many applications, the interaction with the virtual system can be enhanced by the sense of touch, rapid notes can be used to apply the representative powers of the virtual environment to a human user [14,15]. Haptic reactions are also useful in remote surgery, where the main therapist directs surgical instruments but must also provide realistic reactions to the surgeon. While many systems are developed that offer compensatory feedback, many of them fall under the category of advanced search models, which have been developed to provide a specific type of energy feedback appropriate to a particular problem [16,17].

Kinetic analysis is a key point to control the movement of human manipulators, and the main problems are front and rear motor. Above all, the inverse kinetics of the 7-DOF processor have multiple solutions and therefore lead to the problem of obtaining stereoscopic solutions. No detailed research was found in this aspect while some other work was done in design [18], control [19] and avoid obstacles [20] for human manipulators. For serial processors, the reverse motor is much harder than the front drive. In general, methods of reversing kinetic motion can be divided into numerical method, analytical method and geometric method. The numerical method [21,22] is widely used, but can't find all possible solutions. The analytical method [23] [24] can extract all possible solutions while it is more difficult. The engineering method is simple and easy to understand, but it is suitable for only a few types of manipulators [25,26].

This paper presents the design of the ANFIS console to the processor model that was built by the virtual reality environment and simulates this model by connecting Matlab / Simulink with VR to execute commands produced by the system-based ANFIS console. A case study that simulated 7-DOF human manipulator, satisfied results obtained in simulations that improved the design as a basic application of this control system. Introduction to the approach in the first section. The second section presents the kinetic model 7-DOF human manipulator. The third section displays ANFIS control structures and learning methods for ANFIS control. Section V illustrates the real-life model of human arm handling. Section

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IV presents a simulated case study with system design and ultimately conclusion.

II. KINEMATICS OF 7-DOF MANIPULATOR

The front actuators are used to calculate the position of the racquet according to the angles of the joints. It is very useful for analyzing the processor workspace and checking inverse dynamics. Refer to the shoulder width as D, the upper arm length as L_1 and the length of the lower arm as L_2. Next, the position of the shoulder is P1 (0, -D, 0) and the elbow position is P_2 (x_{p2}, y_{p2}, z_{p2}). The corners of the joint are referred to as q_1 ... q_7. Next, the position of the joint i with respect to i-1 can be described by a homogeneous matrix 4 × 4 ${}^{i-1}T_i$ as shown in equation (1).

Suppose that the position of joint 7 in the fixed coordinate is P_3 (x_{p3}, y_{p3}, z_{p3}) and that its position described at RPY (Roll Pitch Yaw) angles is,,,, ψ. Then, position 7 can be described with a homogeneous matrix ${}^0T_7$.

$$\left.\begin{array}{l}
{}^0T_1=\begin{bmatrix} cq_1 & 0 & sq_1 & 0\\ 0 & 1 & 0 & -D\\ -sq_1 & 0 & cq_1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}, {}^1T_2=\begin{bmatrix} 1 & 0 & 0 & 0\\ 0 & cq_2 & -sq_2 & 0\\ 0 & sq_2 & cq_2 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\\
{}^2T_3=\begin{bmatrix} cq_3 & -sq_3 & 0 & 0\\ sq_3 & cq_3 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}, {}^3T_4=\begin{bmatrix} 1 & 0 & 0 & 0\\ 0 & cq_4 & -sq_4 & 0\\ 0 & sq_4 & cq_4 & 0\\ 0 & 0 & 0 & 1\end{bmatrix},\\
, {}^4T_5=\begin{bmatrix} cq_5 & -sq_5 & 0 & 0\\ sq_5 & cq_5 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}, {}^5T_6=\begin{bmatrix} 1 & 0 & 0 & 0\\ 0 & cq_6 & -sq_6 & 0\\ 0 & sq_6 & cq_6 & 0\\ 0 & 0 & 0 & 1\end{bmatrix},\\
{}^6T_7=\begin{bmatrix} cq_7 & 0 & sq_7 & 0\\ 0 & 1 & 0 & -D\\ -sq_7 & 0 & cq_7 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}
\end{array}\right\} \quad (1)$$

Where: $sq_i \equiv \sin(q_i)$; $cq_i \equiv \cos(q_i)$

$${}^0T_7=\begin{bmatrix} c\phi c\theta & c\phi s\theta s\psi - s\phi c\psi & c\phi s\theta c\psi + s\phi s\psi & x_{p3}\\ s\phi c\theta & s\phi s\theta s\psi + c\phi c\psi & s\phi s\theta c\psi - c\phi s\psi & y_{p3}\\ -s\theta & c\theta s\psi & c\theta c\psi & z_{p3}\\ 0 & 0 & 0 & 1\end{bmatrix}$$

(2)

The matrix ${}^0\boldsymbol{T}_7$ also stands for the posture of the racket and it can also be derived as:

$${}^0T_7={}^0T_1{}^1T_2{}^2T_3{}^3T_4{}^4T_5{}^5T_6{}^6T_7\begin{bmatrix} n_x & o_x & a_x & p_x\\ n_y & o_y & a_y & p_y\\ n_z & o_z & a_z & p_z\\ 0 & 0 & 0 & 1\end{bmatrix} \quad (3)$$

According to (1) and (2), the posture of the racket can be calculated as:

$$\left\{\begin{array}{l}
\phi = a\tan 2(n_y, n_x)\\
\theta = a\tan 2(-n_z, c\phi n_x + s\phi n_y)\\
\psi = a\tan 2(s\phi a_x - c\phi a_y, -s\phi o_x + c\phi o_y)\\
x_{p3} = p_x\\
y_{p3} = p_y\\
z_{p3} = p_z
\end{array}\right\} \quad (4)$$

Where atan2 () is the quadratic reverse shadow function and (3) the forward motor of the processor. All commands, such as hitting, hitting and hitting speed of the racquet, are provided in the operating space by the visual system. Must be converted to the link velocity values and the Jacobian matrix is the method used to calculate the velocity of the focal area according to the speed of the operating area. The assignment relationship between them can be described as follows:

$$V = J(q)\dot{q} \quad (5)$$

Where $\boldsymbol{V}$ is the speed of the racket in the operation space and $\dot{q}$ is the joint space speed. $\boldsymbol{J}$ is the 6×7 Jacobian matrix and can be derived by differential transformation method. The i^{th} item of $\boldsymbol{J}$ is:

$$J_i=\begin{bmatrix} (p_i\times n_i)_k\\ (p_i\times o_i)_k\\ (p_i\times o_i)_k\\ n_{ik}\\ o_{ik}\\ a_{ik}\end{bmatrix} \quad (6)$$

Where $\boldsymbol{n_i}(n_{ix}, n_{iy}, n_{iz})$, $\boldsymbol{o_i}(o_{ix}, o_{iy}, o_{iz})$, $\boldsymbol{a_i}(a_{ix}, a_{iy}, a_{iz})$ and $\boldsymbol{p_i}(p_{ix}, p_{iy}, p_{iz})$ are the items of matrix ${}^{i-1}T_i$

$${}^{i-1}T_7={}^{i-1}T_i \ldots\ldots {}^6T_7=\begin{bmatrix} n_x & o_x & a_x & p_x\\ n_y & o_y & a_y & p_y\\ n_z & o_z & a_z & p_z\\ 0 & 0 & 0 & 1\end{bmatrix} \quad (7)$$

The parameter k stands for the rotational axis of joint i. For example, if the joint rotates around the x-axis, then k is x. The racket speed $\boldsymbol{V}$ can be calculated by (4) while the joint space speed $\dot{q}$ cannot be uniquely determined since $\boldsymbol{J}$ is not a square matrix. This problem can be solved hrough the Moore-Penrose method:

$$\dot{q} = J^{+}V \quad (8)$$

Where $J^{+}=(J^TJ)^{-1}J^T$ is the Moore-Penrose pseudo inverse matrix of $\boldsymbol{J}$. The position of the elbow P_2 is in the circle O' whose axis is P_1P_3. The position of the center point

$O^{'}=(x_{O^{'}},y_{O^{'}},z_{O^{'}})$ and the locations of P_1 and P_3 determine the radius (r) and parameters of the length of the arm L_1 and L_2, indicating the level constructed by points P_1, P_2 and P_3 as Ω_1, and the level constructed by points O, P_1 and P_2 is as Ω_2, indicating the separation angle between Ω_1, And Ω_2, as α. Once the position of P_3 is known, the position of the P_2 elbow can be uniquely determined by α. If points O, P_1, and P_3 have a linear relationship while P_1, P_2, and P_3 do not exist, the Ω_2, level does not exist. The angle can be defined as the separation angle between Ω_1, and the horizontal plane. Also, if the P_1, P_2, and P_3 points are nested, the "1" level does not exist and the P_2 position can be calculated according to the P_1 and P_3 positions and the L_1 and L_2 arm length parameters. Given the overall configuration of the processor shown in Figure 1, reversible inverse dynamics can be resolved if angle α and the positions of the racquet are given. According to the characteristics of the movement of human weapons, a mapping relationship between α and the racket position can be constructed without an Internet connection. The unit vector indicating P_3 is referred to as P_1 in the form i (i_1, i_2, i_3) and assume that angle α is computed by the well-trained ANN model, then the circuit can be expressed as follows:

$$\begin{Bmatrix} i_1(x-x_{o^{'}})+i_2(y-y_{o^{'}})+i_3(z-z_{o^{'}})=0 \\ (x-x_{o^{'}})^2+(y-y_{o^{'}})^2+(z-z_{o^{'}})^2=r^2 \end{Bmatrix} \quad (9)$$

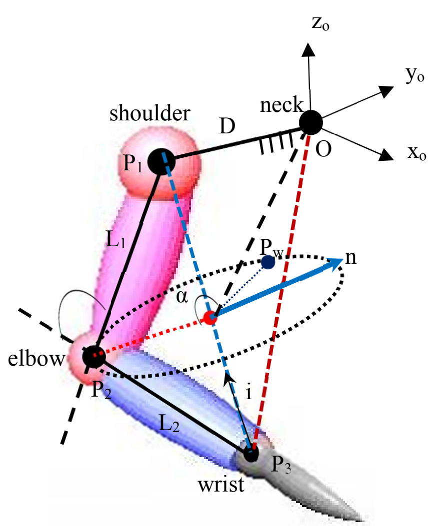

Fig. 1. Configuration of 7-DOF manipulator.

The plane Ω2 and the circle $O^{'}$ intersect at two points. One of the points near the neck is P_w (x_w, y_w, z_w) and angle $\angle P_2O^{'}P_w$ is just the separation angle α between Ω_1 and Ω_2. Denote the norm vector of Ω_2 as $\boldsymbol{n}$ and the position of P_w should satisfy the equation:

$$\overrightarrow{OP_w}.n=0 \quad (10)$$

The position of Pw can be calculated according to (8) and (10). Also, the position of P_2 (x_{p2}, y_{p2}, z_{p2}) satisfies the equation:

$$\sqrt{(x_{p2}-x_m)^2+(y_{p2}-y_m)^2+(z_{p2}-z_m)^2}=2r\sin\frac{\alpha}{2} \quad (11)$$

Position of P_2 can be calculated by (8) and (11). According to the positions of P_1, P_2, P_3 and the cosine theorem, the angle of joint 4 can be calculated as:

$$q_4=\pi-a\cos\left(\frac{L_1^2+L_2^2-\left\|\overline{P_1P_3}\right\|^2}{2L_1L_2}\right) \quad (12)$$

According to the position of P_2, it can be obtained that:

$$\begin{bmatrix}x_{p2} & y_{p2} & z_{p2} & 1\end{bmatrix}^T = {}^0T_1{}^1T_2{}^2T_3\begin{bmatrix}0 & 0 & -L_1 & 1\end{bmatrix}^T \quad (13)$$

Then the angles of joint 1 and joint 2 can be derived as:

$$\left.\begin{matrix} q_1=a\tan 2\left(\frac{-x_{p2}}{cq_2L_1},\frac{-z_{p2}}{cq_2L_1}\right)+k\pi;(k\in N) \\ q_2=a\sin((y_{p2}+D)/L_1) \end{matrix}\right\} \quad (14)$$

Also, according to the position of P3, it can be obtained that:

$$\begin{bmatrix}x_{p3} & y_{p3} & z_{p3} & 1\end{bmatrix}^T = {}^0T_1{}^1T_2{}^2T_3{}^3T_4\begin{bmatrix}0 & 0 & -L_2 & 1\end{bmatrix}^T \quad (15)$$

Then the angle of joint 3 can be derived as:

$$\begin{Bmatrix} q_3=a\tan 2\left(\frac{y_3+D-sq_2L_1-sq_2cq_4L_2}{cq_1cq_2sq_4L_2}sq_1sq_2\right. \\ -\frac{x_3+sq_1cq_2(1+cq_4)L_1}{sq_2cq_1L_1}+ \\ \left.\frac{y_3+D-sq_2L_1}{cq_2sq_4L_2}-\frac{sq_2cq_4}{cq_2sq_4}\right) \end{Bmatrix} \quad (16)$$

According to (2), we have:

Then the angles of joint 5, joint 6, and joint 7 can be derived as:

$$T_5{}^4T_6{}^5T_7^6=\left[T_1{}^0T_2{}^1T_3{}^2T_4^3\right]^{-1}T_7^6=T^* \quad (17)$$

$$\left.\begin{matrix} q_5=a\tan 2(-T_{13}^*,T_{23}^*)+k\pi \qquad (k\in N) \\ q_6=a\tan 2((sq_5T_{13}^*-sq_5T_{23}^*,T_{33}^*) \\ q_7=a\tan 2((-cq_5T_{12}^*-sq_5T_{22}^*,cq_5T_{11}^*+sq_5T_{21}^*) \end{matrix}\right\} \quad (18)$$

Where: T_{ij}^* is th i^{th} row and j^{ij} column item of T

III. GENERAL ANFIS STRUCTURES

ANFIS is an integrated system of the artificial neural network (ANN) and the mysterious inference system (FIS). ANFIS analysis here is first class Takagi Sugeno Fuzzy Model [4], [14]. In the current analysis, there are four inputs: the front obstruction distance (x_1), the right obstacle distance (x_2), the left obstacle distance (x_3) and the target angle (x_4) and the output is the steering angle. If-then rules for an ANFIS structure are specified as follows (see Figure 2);

$$\left.\begin{array}{l} Rule.\ \ IF\ \ x_1\ \ is\ \ A_j;\\ x_2\ \ is\ \ B_k;\ \ x_3\ \ is\ \ C_m\ \ and\ \ x_4\ \ is\ \ D_n\\ THEN\ \ F_i = p_i x_1 + r_i x_2 + s_i x_3 + t_i x_4 \end{array}\right\} \quad (19)$$

Where

$$\left.\begin{array}{l} F_i = p_i x_1 + r_i x_2 + s_i x_3 + t_i x_4 + u_i\\ for\ \ steering\ \ angle\\ J=1\ \ to\ \ q_1;\ \ k=1\ \ to\ \ q_2;\\ m=1\ \ to\ \ q_3;\ \ n=1\ \ to\ \ q_4;\\ and\ \ \ i=1\ \ to\ \ q_1.q_2\ \ \ q_3.q_4 \end{array}\right\} \quad (20)$$

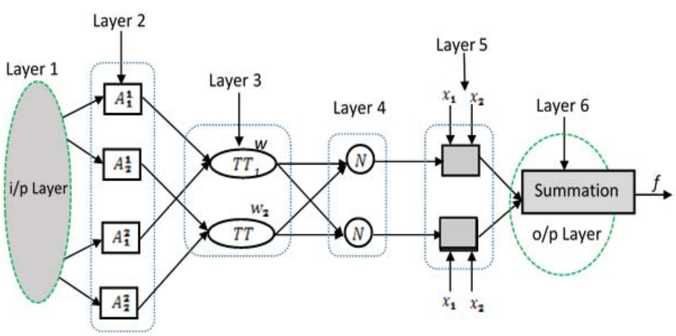

Fig. 2. Structure of six layer ANFIS.

$$\left.\begin{array}{ll} L_{2g}=U_{ag}(x)\ \ for & g=1,....q_1\\ L_{2g}=U_{Bg}(x)\ \ for & g=q_1+1,....q_1+q_2\\ L_{2g}=U_{Cg}(x)\ \ for & g=q_1+q_2+1,....q_1+q_2+q_3\\ L_{2g}=U_{Dg}(x)\ \ for & g=q_1+q_2+q_3+1,....q_1+q_2+q_3+q_4 \end{array}\right\} \quad (21)$$

$$\left.\begin{array}{l} L_{3i}=W_i=U_{ag}(x),U_{Bg}(x),U_{Cg}(x),U_{Cg}(x);\\ For\, i=1,....,q_1+q_2+q_3+q_4\quad and\\ g=1,....,q_1+q_2+q_3+q_4 \end{array}\right\} (22)$$

$$L_{4i}=\overline{W}_i f_i=\frac{W_i}{\sum_{r=1}^{r=q_1.q_2.q_3.q_4} W_r} \quad (23)$$

$$L_{5i}=\overline{W}_i f_i=\overline{W}_i(p_i x_1+r_i x_1+s_i x_3+t_i x_4+u_i) \quad (25)$$

$$L_{6i}=\sum_{r=1}^{r=q_1.q_2.q_3.q_4}\overline{W}_i f_i=\frac{\sum_{i=1}^{i=q_1.q_2.q_3.q_4}\overline{W}_i f_i}{\sum_{i=1}^{i=q_1.q_2.q_3.q_4} W_i} \quad (26)$$

IV. 7-DOF MANIPULATOR BY VIRTUAL REALITY

The design requirements in VRML are explained in limited processing assignments, independence, consistent self-registration, and accountability; each designer should consider these points. An explanation of the design procedures will be provided in VRML. The VRML design depends on the designer's information and the image of the object. There are two options for designing in virtual reality, the first is the standard configuration such as ball, cone, roller, etc., and the second option is free design by selecting the indexed face set button to get many configurations with free reorder points. Each design is therefore a real form as in the second option. The second option starts with building these parts one after the other and verifying the shape of the relevant real maneuvering part. These parts of the processor can't be emulated in virtual reality when the standard format is used in the virtual reality library, where the format is not uniform. Therefore, the design is achieved using the indexed face set in virtual reality. The second option in the design is very important, as the connection between all parts of the design will be achieved for the final object and the origin of the object must be determined. Represents the starting point of the design. This task is done by selecting the first shape (such as the rule) and then connecting the next shape (the second joint) to the Kids button and using the same procedure with the other parts. Figure 3 shows the full design of 7DOF human arm handling.

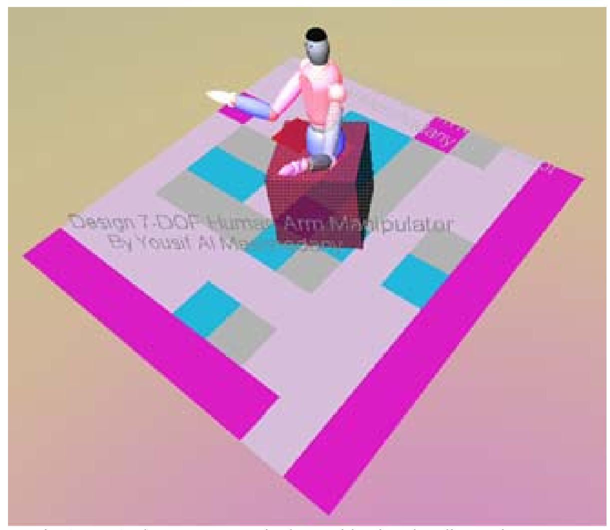

Fig. 3. 7-DOF human arm manipulator with Virtual reality environment.

V. DESIGN ANFIS CONTROLLER FOR 7-DOF MANIPULATOR

The design of the ANFIS 7-DOF controller for the human arm manipulator in this work is considered to be several parameters related to the true values of this system; consider the actual limitation of the human arm joints according to the details. The joint engine is a real engine that functions as a transport function as in equation (1).

$$T.F_m(s)=\frac{1}{s^2+6s+8} \quad (26)$$

Displays the block diagram of the control system in Figure 4. Inputs for system design Two-way orientation and target point position displays values (TT1, TT2, TT3), (Tx, Ty, Tz), respectively. In this technique, each node has a single controller, so seven ANFIS controllers will be used, all of which have the same structure and training algorithm. The training algorithm contains inputs for desired values of the angle separator and the actual values of these angles. The desired values are calculated using the analytical solution of the IKP algorithm that appears in the preceding elements. The actual values of the joint angles get comments from a default model that is executed using VR technology.

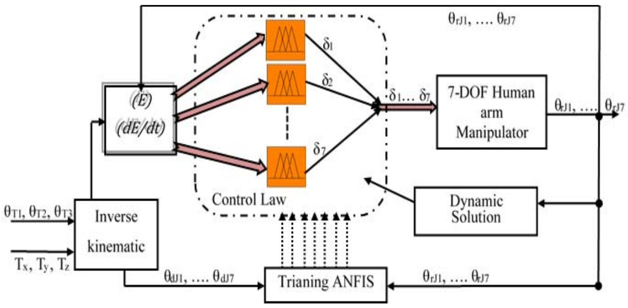

Fig. 4. Block diagram of ANFIS control for 7-DOF human arm manipulator

VI. Simulation Results.

Figure 5 shows the simulation of the ANFIS manipulator graph in this format. In this group, seven ANFIS trainers are used that each of them is used to meet the degree of freedom in the joint which is practically represented by rotating the joint in a particular axis. Seven ANFIS controllers are effective in tracking the desired path, designed for three joints with 7-DOF. Rules of control rules are made from 9 rules and these rules are determined by a mysterious neural network (FNN). The desired position and the direction entered into the simulation as input signal while the actual position of these joints is given by feedback from the output signal. The response to the use of the ANFIS and PID controllers for the joints is tested before the ANFIS console is applied with the default form and the results shown in Figure 5. These results show that ANFIS performance is better than that of PID controllers on a manipulator. The ANFIS control contains fast response and small errors for different ascents via processor path control.

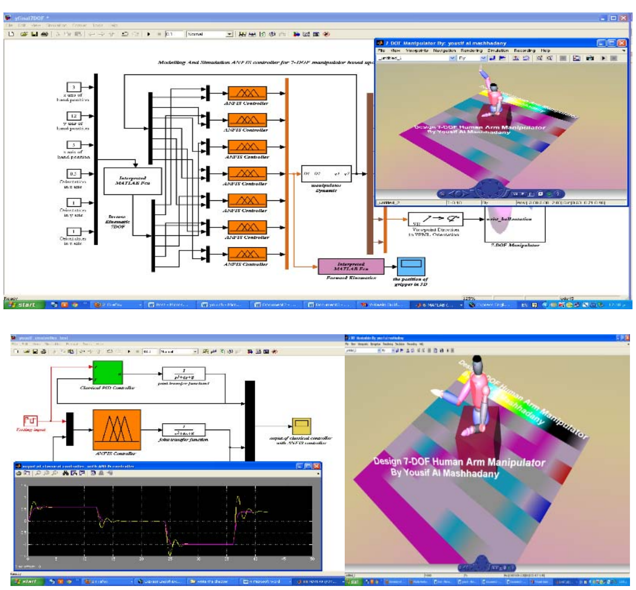

Fig. 5. Simulation of 7-DOF manipulator model based on ANFIS controller

The internal structure of the ANFIS console in the GUI window and in Simulink / Matlab and output the training of the input signal with the different steps used in the motion order provided by the wizard through Figure 6. ANFIS is trained using a mixed-training algorithm with (3.3) Organic and nine bases shown in Figure 6. The length of the time was used to train eighty repetitions per sample with sampling time in Simulink (0.01) seconds.

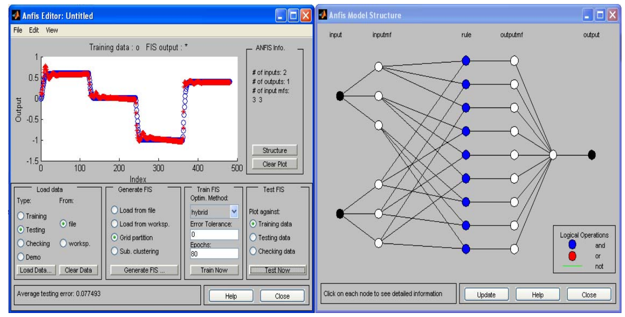

Fig. 6. GUI Matlab for ANFIS structure in Simulink, and its training.

The processor-specific animations are executed using the link between the Simulink / Matlab and VR environment. The order of the animation is achieved by Matlab and Simulink. Then, send this request to a VR model to execute, taking into consideration the different axes between Matlab axes and VR axes for real movement such as general movement: bending / elbow extension, elbow rotation, Shoulder abduction, flexion / shoulder extension, inner / outer gyro of the shoulder, flexion / wrist extension, ulnar / radial deviation, curvature / horizontal extension of the shoulder. Or special procedure such as arm access to the head level, arm access to the right, head level, arm reach to the left, head level, and arm reaching to the right. Examples of these movements are given in figure 7.

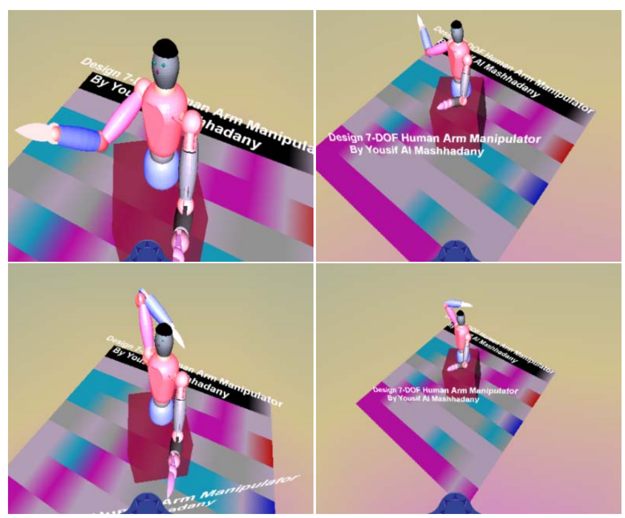

Fig. 7. 7-DOF manipulator model implement a different postures based on ANFIS controller.

VII. CONCLUSION

The objective of the ANFIS-based control module is to overcome the general problems of the mysterious system and the neural network with a dynamic system. The training of the ANFIS depends on the experiment and error of all elements (foggy interference types, organic function types, number of neurons, and number of bases) for high performance using the output position manipulator. This controller is compared to the classic PID control for speed tracking and link angle accuracy. The following are the main conclusions based on the simulation results: ANFIS has better transient and constant state responses than the PID controller in the full speed range, while the P1 control unit in the best tuning state is unable to control both slow and high-speed speed. It is simpler than adaptive blurry controls in many researches. In other words, it contains only 9 neurons, 4 layers, and 9 rules. Does not require a precise model of the plant, it is relatively simple and therefore its construction and implementation is fairly easy. It does not require high knowledge with the system to create a set of rules such as a fuzzy controller or can be specified in a neural network controller. ANFIS control was used to control the movement of many manipulators in both simulation and experimental mode. A 7-DOF dynamic analysis of the processor helps to give the processor envelope account similar. The Manipulator application in virtual reality environments is extremely accurate and reliable with many applications in the development of high-precision processing devices such as manufacturing very small equipment that need to collect many small items at the same time.

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