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Using Sugeno Fuzzy Controller for Trajectory Tracking Control of Scara Robot Manipulator

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ABSTRACT

The main aim of using robots is to increase in quality, productivity, and flexibility. Building a dynamic robot model is difficult for several reasons, including the complexity of the mathematical model, nonlinearity, and uneven time. The complexity of the issue increases as the degrees of freedom (n^{th}) increase (DOF).

In recent years, the concept of artificial intelligence has emerged as a solution to achieve accuracy and speed Which in turn contributed to building sophisticated robots capable of performing complex tasks optimally. The research suggests using a Fuzzy Logic algorithm (FL) to control the SCARA robot path through analysis and derivation of the front and back movement parameters of a known trajectory using Sugeno fuzzy model.

The simulation results proved that the proposed fuzzy controller has good performances such as fast response and small errors for different desired trajectory functions and it can be extended to more degree-of-freedom robotic arm systems.

***Keywords* :—** SCARA Robot Manipulator, Sugeno fuzzy controller, Trajectory Tracking.

I. INTRODUCTION

Robotic manipulations are generally used to perform tasks that are difficult for humans to perform such as dangerous tasks in laboratories, mines, in the nuclear power plant, and repetitive jobs that are boring, stressful, or labor-intensive for humans. All of the above requires accuracy and speed at the same time.

SCARA Robot is a popular manipulator, which is tailored for assembly operations. It was proposed as a means to provide motion capabilities to the end effector that is required by the assembly of printed-board circuits and other electronic devices with a flat geometry. SCARA has two parallel revolute joints (allowing it to move and orient in a plane), with a third prismatic joint for moving the end effector normal to the plane. The main advantage is that the first two joints don't have to support any of the weight of the manipulator or the load. In addition, The actuators can be made very large, so the robot can move very fast [1].

Robot manipulators represent complex dynamic systems with extremely variable inner parameters as well as the large intensive contact with the environment. An accurate control of such a complex system deals with the problem of uncertainty. The direct implementation of control in the control system of a real manipulator is impossible without obtained correct dynamic model[1,2].

Fuzzy logic controller (FLC) was found to be an efficient tool to control nonlinear systems; many applications of fuzzy logic control are reported in the various engineering fields including industrial processes and consumer products.

Many model-based fuzzy control approaches are applied in robotics category such as Mamdani models and Sugeno models [3].

II. CONTROLLING ROBOT MANIPULATORS LITERATURE REVIEW

(St. Joseph's, in 2005) described a fuzzy position control scheme designed for precise tracking of robot manipulator, but the error of tracking Relatively large [3].

(Zhi-Wei Yang, in 2008) developed an adaptive fuzzy-neural network control for an n-link robot manipulator to achieve high-precision position tracking. using Sugeno dynamic fuzzy model with on-line learning ability constructed for representing the system dynamics of an n-link robot manipulator. Simulations of a two-link robot manipulator via (AFNNC) showed the high performance and the high accuracy of the proposed controller [4].

(Tinkir , et, in 2011) designed an adaptive neural network based interval type-2 fuzzy logic controller (ANNFL), circular and handwriting type trajectory planning was proposed to show the ability of a SCARA type robot manipulator. The researcher realized that the Cartesian trajectory tracking control of SCARA robot by using (ANNFL) and PID controller. They found that the performances of ANNFL controller have good, such that fast response and small errors for different rise function over circular tool trajectory control, and better than PID controllers performances over SCARA robot. But the trajectory tracking figure shows that the error of tracking needs to be minimized [5].

(Majid Alaei, et, in 2011) introduced a Neuro-Fuzzy Controller (NFC) for trajectory tracking control of robot arm. From the simulation results, they found that Neuro–Fuzzy controllers provided good performance for control of robot manipulators [6].

III. DESIGN MODEL OF SCARA ROBOT MANIPULATOR

Designing a Model system that takes a desired function for SCARA robot "sinusoidal for the two revolute joints, and linear function for the prismatic joint" as input and gives the appropriate output is the goal of this research. The outputs are the position and the velocity of the robot. Sugeno controller is used to perform control algorithm, the steps used to solve this problem is designing a control system that takes a desired function for SCARA robot "sinusoidal for the two revolute joints, and linear function for the prismatic joint" as input and gives the appropriate output is the goal of this research. The outputs are the position and the velocity of the robot. The steps used to solve this problem are:

A. Kinematic Model for Robot Manipulator:

By using Lagrange Euler formulation, which is based on the concepts of generalized coordinates, energy and generalized force are obtained. There are mainly two types of problems in the kinematic of the robot manipulator; the forward and inverse kinematic [1].

- **Forward Kinematic:**

1. Consideration and Assumptions:To give a brief description of the considered robot manipulator we should allocate the different frames attached to the robot body, and briefly explain the proposed parameterization. Fig. 1 shows the Coordinate frames attached to SCARA manipulator [2].

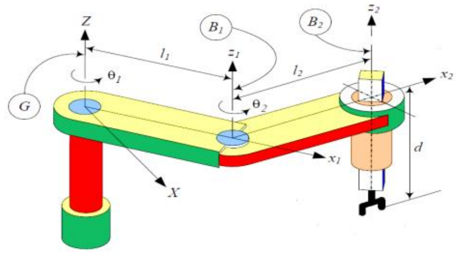

Fig. 1 Coordinate frames attached to SCARA manipulator

   - Center of mass of link-1 is allocated at (lc1) from (θ1) in the direction of (x1) .
   - Center of mass of link-2 is allocated at (lc2) from (θ2) in the direction of (x2) .
   - Center of mass of link-3 is allocated at (θ3) .
   - Link-1 has mass and inertia tensor (lc1).
   - Link-2 has mass and inertia tensor (lc2).
   - Link-3 has mass and inertia tensor (lc3).
2. Derivation of link transformations matrices: To construct the transform that defines frame *i* relative to frame *i-1*.
3. Concatenating link transformations matrix: It is a very important step, to calculate the position and orientation of the end-effector of the manipulator. Once the link frameworks have been calculated and corresponding link parameters defined, developing the kinematic equation is modest and straightforward. From the values of the link parameters, the individual link transformation matrices can be computed.

- **Inverse Kinematic:**

Inverse kinematic is concerned with the inverse problem of finding the joint variable in term of the end-effector position and orientation. Solving the inverse kinematics is computationally expensive and generally takes more time in real-time control than the forward kinematics problem. For robot manipulator, the following steps have been followed:

1. Obtaining the general transformation matrix for the desired position and orientation of the robot manipulator.
2. For both matrices, defining: All elements that contain one joint variable, Pairs of elements, and Combinations of elements contain more than one joint.
3. Equating it to the corresponding elements in the other matrix to form equation, and then solve these equations to find the values of joint variables.
4. Repeating step (3) to identify all elements in the two matrices.
5. In the case of inaccuracy, solutions looking for another one.
6. If there is more joint variable it can be found by the inverse of the matrix for the specified links in step (1).
7. Repeating steps (2) through (6) until a solution to all joint variables has been found [1.2].

B. Dynamic Model for Robot Manipulator:

The dynamic behavior is described in terms of the time rate of change of the arm configuration in relation to the joint torque exerted by the actuators. This relationship can be expressed by a set of differential equations, called equations of motion, that govern the dynamic response of the arm linkage to input joint torque. The system's dynamical behavior is described using Lagrange formulation in term of work and energy using generalized coordinates. The Lagrangian formulation is used in this research to derive the dynamical model of robot manipulators.

Finally SCARA robot has been represented by a mathematical model with three input driving torques and six output variables, three angle displacements for the three joints, and three angular velocities, in practice the final goal of controlling a manipulator is to put the end-effector at some specific [2].

IV. DESIGN THE FUZZY CONTROLLER FOR SCARA ROBOT

The principal design elements in a general fuzzy logic control are Fuzzification, Control rule base establishment, and Defuzzification as shown in Fig. 2. The fuzzifier converts the crisp input to a linguistic variable using the membership functions stored in the fuzzy knowledge base. The rule base holds the knowledge, in the form of a set of rules, of how best to control the system. The inference mechanism determines the extent to which each rule is relevant to the current situation as characterized by the input and draws decisions using the current inputs and the information in the rule-base. And the defuzzifier converts the fuzzy output of the inference mechanism to a crisp using membership functions into crisp values.

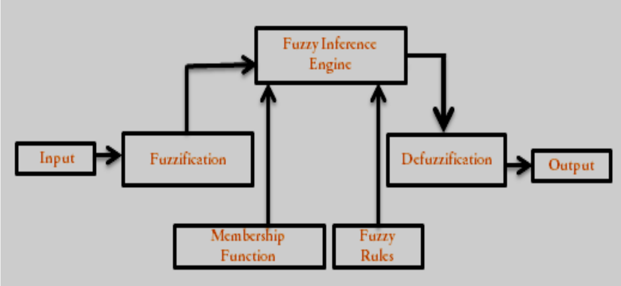

Fig. 2. Model of Fuzzy Inference Processing

Fuzzy inference mechanism process is obtaining the relevant control rule at the current time then decides the behavior of the output. Fuzzy inference system uses a collection of fuzzy membership functions (MFs) and rules; it uses If-Then fuzzy rules to convert the fuzzy input to the fuzzy output.The most popular methods to form the If-Then rules are Mamdani and Sugeno.

The two methods have the same antecedent evaluation of the If-Then statement. But the main difference between the two is the consequent, where the consequent in Mamdani depends on the designer or the human operator, but in Sugeno, the consequent is a function of real value. IN this search Sugeno fuzzy model is adopted to construct the fuzzy model of the system, due to its capability to approximate any nonlinear behavior.

the inputs of FLC are the measured (Error) and Derivative of error (D-Error) of the position. They are scaled to some numbers in the interval [-90 90], these values indicate to the angle of rotation, and are mapped to linguistic variables by fuzzification operator. The values of linguistic variables are composed of linguistic terms which are fuzzy sets. The Fuzzy Control Model used here is Sugeno model.

The fuzzy rule is represented by a sequence of the form If-Then, leading to algorithms describing what action or output should be taken. In the proposed FLC, twenty-five rules recommended achieving the tracking. Fuzzy control rules for the designed controller are listed in TABLE I.

The fuzzy control rules of the proposed controller have been derived experimentally from studying and observe the response of the process to be controlled. The twenty-five rules have been derived by the multiplication of the numbers of membership functions of the two inputs [7,8]

TABLE II

Fuzzy control Rules

Error/D-Error	NL	NS	ZE	PS	PL
NL	NL	NL	NL	NS	ZE
NS	NL	NL	NS	ZE	PS
ZE	NL	NS	ZE	PS	PL
PS	NS	ZE	PS	PL	PL
PL	ZE	PS	PL	PL	PL

V. SIMULATION AND RESULTS

SIMULINK MATLAB is used to simulate The dynamic model (Nonlinear System and Nonlinear Feedback System) of the SCARA robot manipulator and to evaluate the performance of the proposed controller that applied on it [9,10].

Figure. 3 show the position tracking curve of the first joint, the blue curve is the desired path while the red is the actual. Sinusoidal function was chosen as a desired trajectory.

figure. 3 shows that the first joint tracks the desired path accurately,with very small error as shown in figure (4).

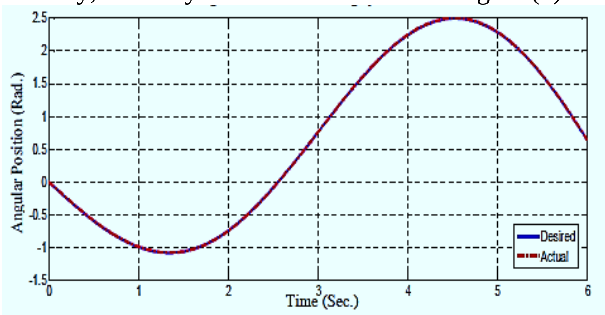

Fig.3 Position Tracking Curve of the First Joint

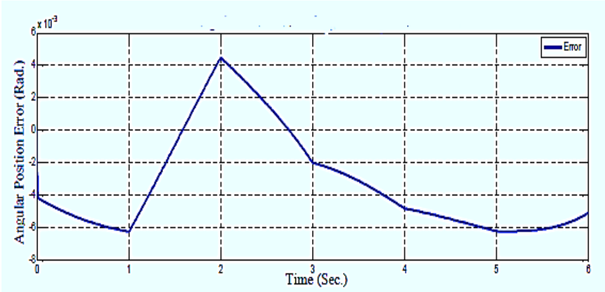

Fig.4 Position Tracking Error Curve of the First Joint

Figure. 5 shows the position tracking curve of the second joint, the same desired trajectory for the first joint chosen for second joint.

Also the figure. 5 shows that the second joint tracks the desired path accurately, with very small tracking error as shown in figure. 6.

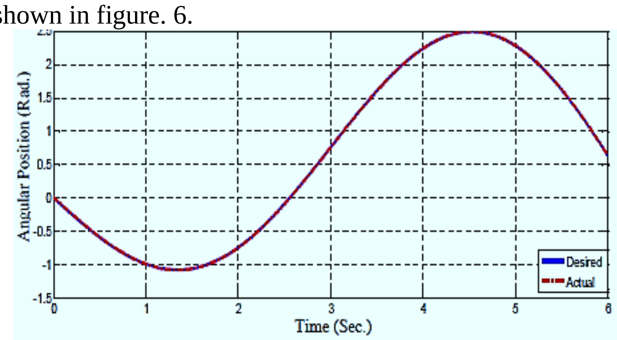

Fig. 5 Position Tracking Curve of the second Joint

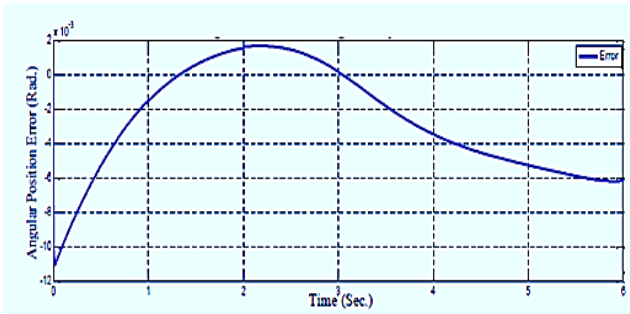

Fig. 6 Position Tracking Error Curve of the second Joint

Figure.7 shows the position tracking curve of the third joint, a linear function was chosen as a desired trajectory.
As the figure.7 show, the third joint tracks the desired path accurately, with very small error as shown in figure. 8.

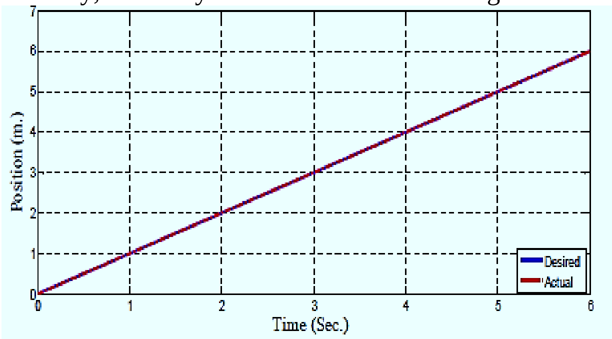

Fig. 7 Position Tracking Curve of the third Joint

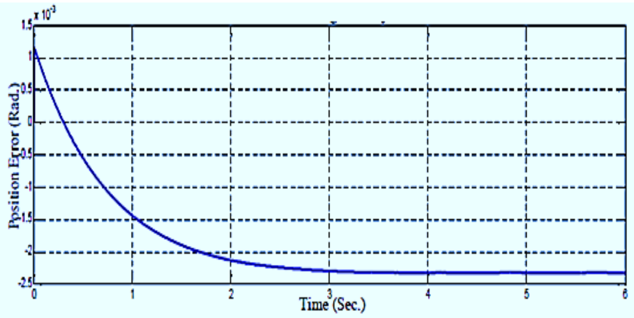

Fig.8 Position Tracking Error Curve of the third Joint

Figure 9 shows the velocity tracking curve of the first joint, the derivative of the position desired function was taken as a desired velocity trajectory. The velocity tracking error is very small as shown in figure. 10.

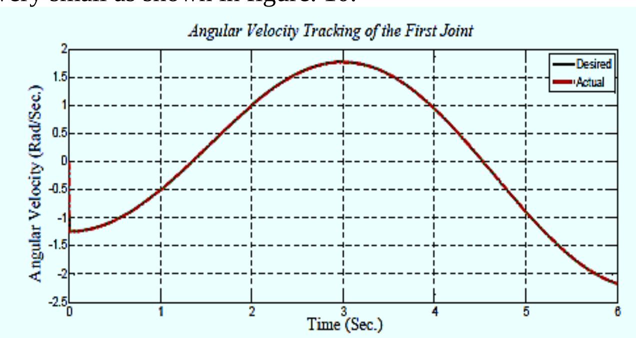

Fig. 9 Velocity Tracking Curve of the First Joint

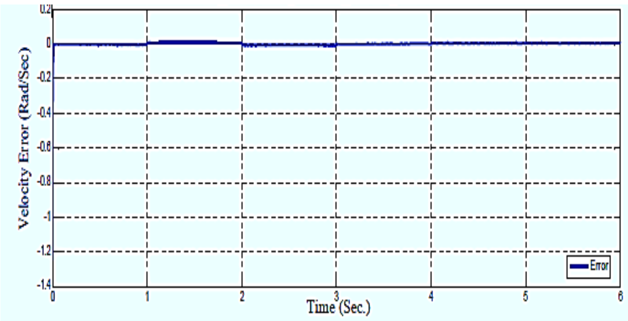

Fig. 10 Velocity Tracking Error Curve of the First Joint

Figure.11 shows the velocity tracking curve of the second joint, the derivative of the position desired function was taken as a desired velocity trajectory. The velocity tracking error of the second joint is very small as shown in figure.12

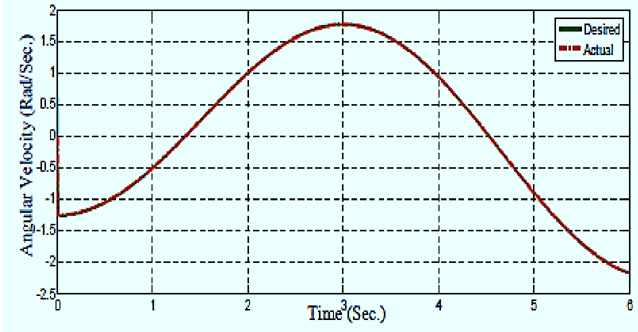

Fig.11 Velocity Tracking Curve of the second Joint

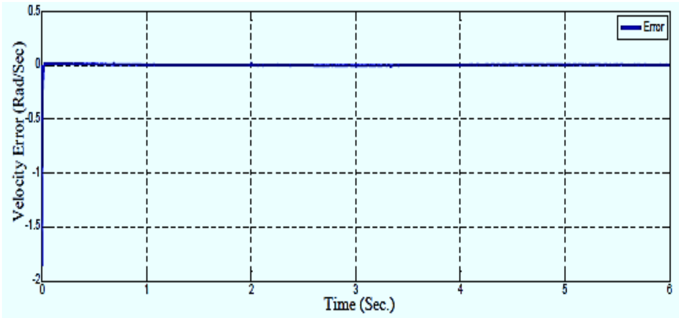

Fig. 22Velocity Tracking Error Curve of the second Joint

Figure. 13 shows the velocity tracking curve of the third joint, also the derivative of the position desired function was taken as a desired velocity trajectory. The velocity tracking error of the second joint is very small as shown in figure. 14

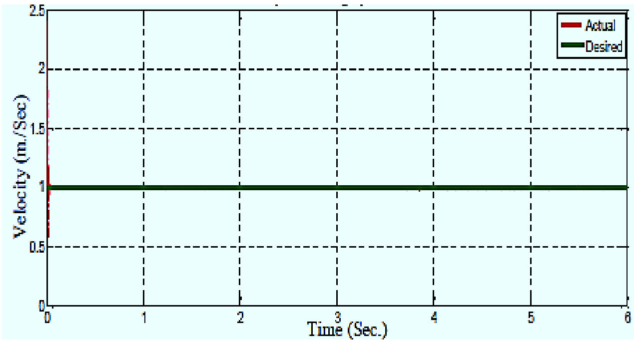

Fig. 13 Velocity Tracking Curve of the third Joint

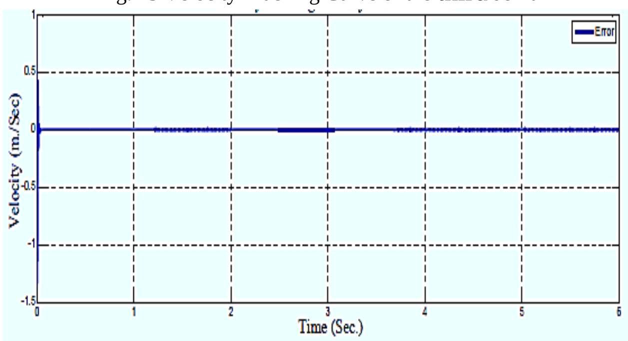

Fig. 34 Velocity Tracking Error Curve of the third Joint

V. CONCLUSIONS AND CONTRIBUTION

- the error generated from the use sugino fuzzy model is very small comparing with the errors in the other methods.In [5] the position tracking error is "0.1". The results in [3] shows that the position tracking error is about "0.2" while the velocity tracking error is about "0.1". While in this work the error is very small; it is "0.012" at most for different desired trajectory functions.
- In this research, we have reached todesign control system for SCARA robot arm to track the desired path with minimum error aims to identify the parameters of the robot, derive the mathematical model of the robot, and use algorithm of Sugeno fuzzy model for Trajectory Tracking Control of SCARA Robot Manipulator and make it to tracks the desired path accurately.
- Finally this work can be extended to more degree-of-freedom robotic arm systems.

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