Fuzzy Logic Trajectory Control of Flexible Robot Manipulator With Rotating Prismatic Joint

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***Abstract*— In this study, a fuzzy logic controller is designed in order to use in trajectory control of a robot manipulator. The considered robot manipulator consists of a rotating-prismatic joint housing a sliding flexible arm that carries a concentrated mass at the tip end. The tip end of the flexible arm traces a multi-straight-line path. This study is aimed to use a fuzzy logic controller in controlling the trajectory traced by the tip end of the flexible arm so as to reduce the vibrations induced in the flexible arm. The designed fuzzy controller is aimed to control both the position of the tip end of the flexible robot arm while the tip end traces a multi-straight-line path and the vibrations induced in the flexible arm. Numerical simulations obtained by using a developed computer program are presented and physical trend of obtained numerical results are discussed. The performance of the fuzzy logic control system is evaluated on the basis of the simulation results.**

Keywords - Flexible robot arm, fuzzy logic controller, straight line path, multi straight line path, trajectory control, rotating prismatic joint, vibration control.

I. INTRODUCTION

In many industrial and aerospace applications, robots have been found to be useful in performing some repetitious, labour-intensive, dangerous, monotonous, and tedious jobs. Robot are also useful in applications performed in hazardous or hostile environments such as arc welding shops, contaminated areas, nuclear reactors, outer space, and under water. In some cases, the presently available robots are not fast enough, economical or sufficiently accurate. This reality increased the demand for lighter weight robots with more accurate position control and larger payloads. So, future robots are expected to have more flexible members. In such cases, structural flexibility must be considered in design of robotic control systems with additional requirements for higher speed, better system performance, lower power consumption and cheaper operating costs. Therefore, research on the dynamic modelling and control of flexible robots has received increased attention in the last decades. A first step towards designing an efficient control strategy for manipulators with flexible links must be aimed at developing dynamic models that can characterize the flexibility of the links accurately. The controller design that minimizes the effects of the flexible displacements in lightweight robots is highly demanded in many industrial and space applications that require accurate trajectory control. In control applications of robot manipulators with flexible arms are targeted either to reach a target position or to follow a prescribed trajectory. In the first case to reach a target position, a short settling time is desired while a large robot arm displacement is planned in the second case to follow a prescribed trajectory. In both case, strong control actions are applied to the robot arm and as a result, undesired behaviours could appear if vibrations induced in the robot arm are not considered.

Existing studies on flexible robot manipulators can be divided into two categories with regards to the joint type: Those with revolute joint, and those with prismatic joint. Most of the investigations consider flexible arms with revolute joints [1-13]. Flexible robot arm sliding in a prismatic joint can be seen in many engineering applications such as some industrial robots, loading vehicles with telescopic members, space craft antenna, magnetic tape drivers, printers, flexible transmission lines, band saws, and weaving mechanisms. Some investigators investigated dynamics of flexible robot arms sliding in prismatic joints [14, 15]. Flexible members sliding in prismatic joints are known to produce considerable mathematical difficulty in dynamic modelling of such systems. The problem becomes even more difficult if the prismatic joint rotates. It is evident that a reliable dynamic model for a flexible robot arm sliding in a rotating prismatic joint that accounts for the

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interaction between rigid and flexible body motions is highly demanded. Such a dynamic model is crucial to the design, performance evaluation, and control of light-weight, high-speed, and high-precision applications. Research on the fuzzy logic control (FLC) of robot manipulators has received increased attention in the last decades due to its several advantages over other control techniques. FLC is generally used in control of rigid link robot arms sliding in prismatic joint [26-29] or flexible link robot arms with revolute joints [29-41]. Some other techniques besides FLC are also used in control of flexible link robot manipulators with prismatic joints [17-26].

The aim of this study is applying fuzzy logic control to a flexible arm whose tip end traces a multi-straight-line path. Considered robot manipulator consists of a rotating-prismatic joint and a sliding flexible arm assumed to be an Euler-Bernoulli beam. The flexible arm is assumed to carry an end-mass. The flexible arm is under the action of an external driving torque and an axial force. Equations of motion of the flexible manipulator are obtained by using Lagrange's equation of motion. In the formulation, the prismatic joint is treated as rigid. The flexible arm is housed inside the rigid prismatic joint. Effect of rotary inertia, axial shortening and gravitation is considered in the analysis. The fuzzy logic based control is aimed to control both the position of the tip end of the flexible robot arm while the tip end traces a multi-straight-line path and the vibrations induced in the flexible arm.

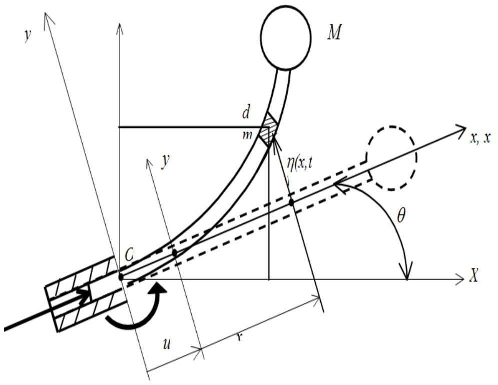

Fig. 1. Flexible robot manipulator with rotating-prismatic joint.

II. DYNAMIC MODELLING OF THE FLEXIBLE ROBOT MANIPULATOR

The physical configuration of the flexible robot manipulator considered in this study is given in Fig. 1. The flexible arm is assumed to be an Euler-Bernoulli beam. The mass and flexible properties are assumed to be distributed uniformly along the flexible arm. The prismatic joint is assumed to be rigid. The flexible arm slides in the prismatic joint under the action of axial force F. The sliding motion of the flexible manipulator is assumed to be frictionless. The initial length of the beam is denoted as l_0 and the elongation in the length of the manipulator is denoted as u. Torque T, rotates the prismatic joint about Z axis. The flexible arm experiences a combination of rotational and translational gross motion. XYZ is the global reference frame, while $x^{/}y^{/}z^{/}$ is the rotating and xyz is the rotating and translating reference frame.

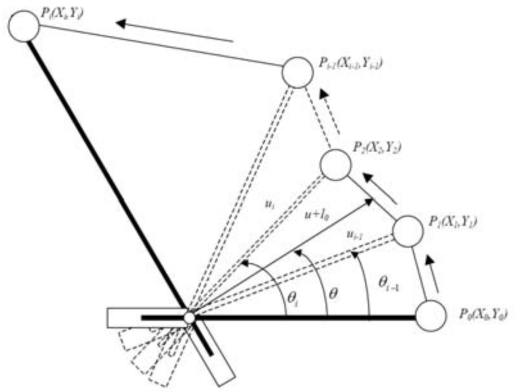

Fig. 2. Flexible robot manipulator following multi-straight-line path.

Angle between the rotating reference frame $x^{/}y^{/}z^{/}$ and the global reference frame XYZ is denoted as θ. Distance of dm to the origin in x direction is $u+x$ and the displacement from the undeformed position in y direction is denoted as η. A flexible robot manipulator tracing a straight-line path through prescribed points P_0, P_1, ..., P_i is seen in Fig. 2. Tip of the flexible manipulator experinces P_0P_1, P_1P_2, ..., $P_{i-1}P_i$,… straight-line paths respectively. Joint angle θ varies continously during the motion. Value of θ starts from 0 and varies depending on the input function fed through a servomotor. In order to trace a linear path, length of the flexible manipulator is varied depending on θ and so by time. This fact necessitates the determination of variation of length of the flexible manipulator. From Fig. 2, u, $\dot{u}$ and $\ddot{u}$ are can be expressed as in [16]:

III. FUZZY LOGIC CONTROLLER DESIGN

Studies in the field of fuzzy systems and control have been making a big progress motivated by the practical success achieved in industrial process control applications. Fuzzy systems can be used either as open-loop controllers or closed-loop controllers, as shown in Fig. 3. When used as a closed-loop controller, the fuzzy system measures the outputs of the process and takes control actions on the process continuously. Applications of fuzzy systems in industrial processes belong to this category. The fuzzy controller uses a form of quantification of imprecise information (input fuzzy sets) to generate by an inference scheme, which is based on a knowledge base of control force to be applied on the system [42].

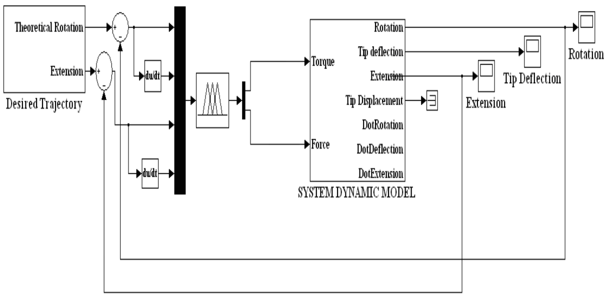

Fig. 3. Block diagram of fuzzy logic control for flexible robot manipulator with rotating-prismatic joint.

Two of the difficulties in the design of fuzzy control systems are to generate the membership functions and choose of the fuzzy rules. In fact, the decision-making logic is the way in which the controller output is generated. It uses the input fuzzy sets, and the decision is taking according to the values of the inputs. Moreover, the knowledge base comprises knowledge of application domain and the attendant control goals.

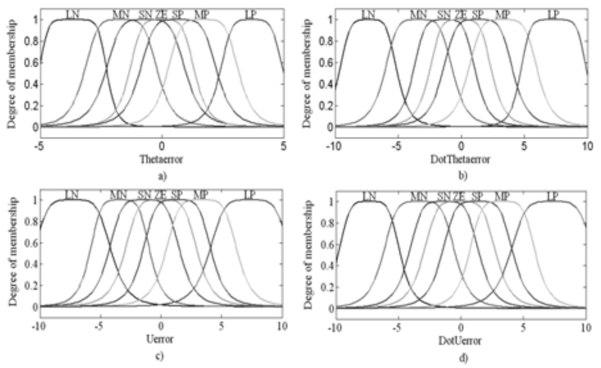

Fig. 4. Membership functions of inputs for fuzzy logic controller

a) Error input, $U_{\theta e}$ [rad] b) Change in error input, $U_{d\theta e}$ [rad]
c) Error input, U_{ue} [m] d) Change in error input, U_{due} [m]

It consists of a database and a fuzzy control rule base. A control system is said to be an adaptive fuzzy control system if either a set of fuzzy rules are used to modify or change an existing fuzzy controller's architecture, i.e., membership functions and/or rules [42]. The fuzzification uses membership functions to determine the degree of inputs. The aim of control action is to minimize the trajectory tracking error. The higher the error, the higher the control input. However, the rate of change of error also affects the value of the control input. In fuzzy logic controller, error and change in error rate are used in control rules as linguistic variables. The fuzzy membership functions for the rotation error ($U_{\theta e}$), change in rotation error ($U_{d\theta e}$), extension error (U_{ue}), change in extension error (U_{due}) and outputs (T_s, F_s) are shown in Fig. 4 and 5, respectively.

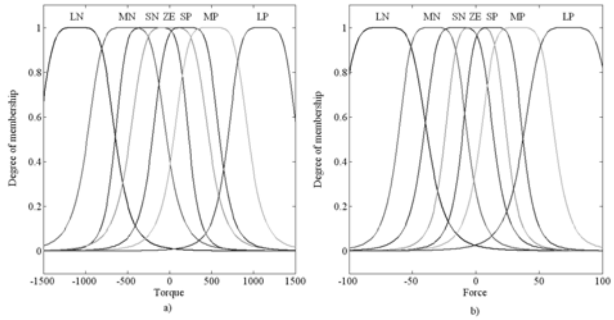

Fig. 5. Membership functions of outputs for fuzzy logic controller

a) Torque output, T_s [Nm] b) Force output, F_s [N]

IV. RESULTS AND DISCUSSION

The tip of the flexible manipulator is located at P_0 at the beginning of the motion and moves to P_2 along a multi-straight-line path, passing through the prescribed intermediate point P_1. Variation of $u+l_0$ versus time in order to trace the prescribed path is determined and given in Fig. 6. As seen from Fig. 6, the curve for $u+l_0$ consists of two piecewise continuous regions. Simulation results obtained for reference input values of rotational and extension motions in the FLC case are in good agreement with the calculated results as shown in Figs. 6 and 7. Quite small errors, which can be neglected, for tracking reference input signals occur in the simulations. Considering obtained results it can be seen that by using a fuzzy logic controller the system tracks the reference trajectory with high accuracy.

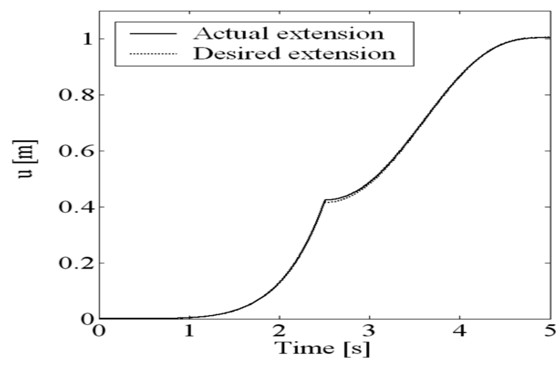

Fig. 6. Variation of length of flexible manipulator.

The FLC has been optimized to reduce the rotation and extension tracking error. The FLC tracks the calculated reference trajectory almost perfectly without extreme phase difference. The rotation and extension position tracking is realized using same rate of shortening/ extension rates. The

FLC shows good performance especially with a much smaller total motion time.In Fig. 8, the trajectory traced in P_0P_1 and P_1P_2 regions by the tip end of the flexible manipulator for the total motion time t_p=5 s are given. The path tracking performance, seen in Fig. 8, is near perfect and precise. Plot of tip displacement of the flexible manipulator is given in Fig. 9. Plot of tip deflection of flexible arm contains two characteristic regions. Since, change of u is dissimilar for P_0P_1 and P_1P_2 paths, characteristics of the vibration of the flexible arm in P_0P_1 path and P_1P_2 path are distinct.

V. CONCLUSIONS

Fuzzy logic control of a flexible robot arm sliding in a rotating-prismatic joint is investigated. The tip end of the flexible manipulator is assumed to trace a multi-straight-line path passing through prescribed points.

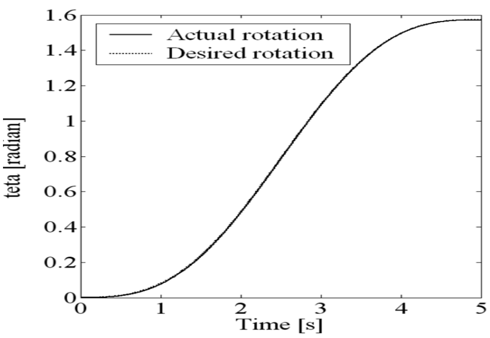

Fig. 7. Angular position of servo motor.

The flexible arm is under the action of an external driving torque and an axial force. The flexible robot arm is carrying an end mass. Control of vibration and position of the tip end of the flexible robot arm is realized successfully by fuzzy based control approach while the tip end traces a multi-straight-line path. Numerical simulations obtained by using a developed computer program are presented and physical trend of the results are discussed. The performance of the fuzzy logic control system is evaluated on the basis of the simulation results. Simulation results obtained for the flexible manipulator illustrates a successful performance of the designed controller. The fuzzy logic controller (FLC) has been optimized to reduce the rotation and extension tracking error. Simulation results obtained for reference input values of rotational and extension motions in the FLC case are in good agreement with the calculated results. Quite small errors, which can be neglected, for tracking reference input signals occur in the simulations. The FLC tracks the calculated reference trajectory almost perfectly without extreme phase difference. The FLC has good performance, especially with a much smaller total motion time.

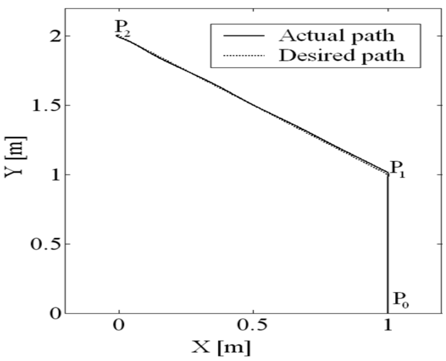

Fig. 8. End-effector path in the Cartesian space.

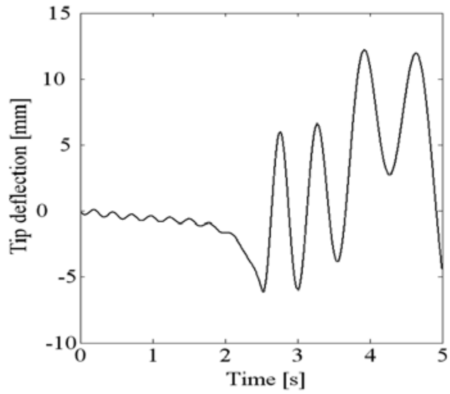

Fig. 9. Tip deflection of flexible manipulator.

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