Microsteping Control of Hybrid Stepper Motor Using Fuzzy Logic for Robotics Application

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Abstract: The work on this paper focuses on the design of high accuracy and high performance of positioning tracking controller of the Hybrid stepper system (HSM), realized for the application of direct drive robot (DDR). The control problems characterized by mathematical models exhibit significant nonlinearity and uncertainty. Also high tracking performance requires that the actual system trajectory matches the desired trajectory as close as possible. Fuzzy logic control (FLC) has been used widely in many practical and industrial applications with large degree of uncertainty and nonlinearity. The design of this position tracking system based on microstepping controlled HSM is achieved by implementation of FLC techniques. Simulation results have been carried out to test the performance of the controlled system.

1.Introduction

Step motors are incremental - motion actuators. They are generally used in microcomputer, office and factory automation applications, and now they are widely used in robotics. Since the hybrid step motor has higher efficiencies, maintain very high resolution due to the small step angle and other advantages over the variable -reluctance, and permanent-magnet type stepping motors, they are the most commonly used stepping motors in industry [1-2]. The main appeal of HSM in robotics is their use as direct drive actuators.

Direct drive robot consists of a mechanical arm with electrical motors directly coupled to the joints. The absence of conventional transmission mechanism between the motor and their loads provides several advantages such as no blacklash, low friction, and high stiffness. These feature have a favorable impact on the performance of precision positioning robots for trajectory control. The electrical design of a direct drive robot seems to have been studied much less [3]. Brushless motors well suited to this application are of two types: the permanent-magnet synchronous motor and the switched reluctance motor. The motor used in the prototype built in this work is a hybrid step motor, which combines the design principle of the variable-reluctance , and permanent-magnet motors.

Speed and position regulation, speed and position tracking, or torque and force control are major areas of interest in motion control in robotics [4].

In this work we presented and described design of position tracking control system for direct drive robot. The directions of this work are summarized as follows:

First, initial steps are taken towards the development of a mathematical modeling of the controlled system. Presentation of the simulation results of the dynamic performance of the system is shown.

Second, a Fuzzy logic technique is used to design the trajectory control for a class of electromechanical system. The fuzzy trajectory controller (FTC) is responsible of reducing the effect of uncertainty in the load and it is based on microstepping controlled HSM. The input to this controller is the desired position trajectory and the feedback signal represent the actual position of the system. The output from this controller is the control signal which represent the switching pulses per sec (frequency) of the driving unit of the HSM to keep track of the number of motor steps or pulses per second.

Finally a prototype implementation for position tracking system of the HSM is described. Simulation results are presented for the trajectory controller performance to show that the design objective of the FTC has been met.

2. Hybrid Step Motor Design.

Hybrid step motors (HSM) combine the principles operation of the variable reluctance motor and the permanent magnet type of step motors. The rotor consists of a permanent magnet (PM) that is magnetized parallel to the shaft axis to create a pair of poles. On this magnet, two end caps are fitted at both ends. These end caps consist of equal number of teeth N_r. The stator is one single unit (laminated) where the winding slots are parallel to the motor shaft. Torque in a HSM is produced by interaction of the rotor-and the stator produced fields. The rotor field is produced by PM and hence stays constant. The stator field and therefore T_e is proportional to the phase current. There are two excitation modes of operation. The single-phase excitation, where each of the stator phases is exited one at a time and the rotor moves by a step for each change in excitation. The two-phase excitation, where two of the stator phases are simultaneously excited to provide a better damping of the rotor. The HSM with the driving power unit is shown in fig. 1.

3. Mathematical Model of the Controlled System.

The objective in this section is the development of a nonlinear mathematical model that includes the dynamics of the HSM a well as the dynamics of the robot manipulator.

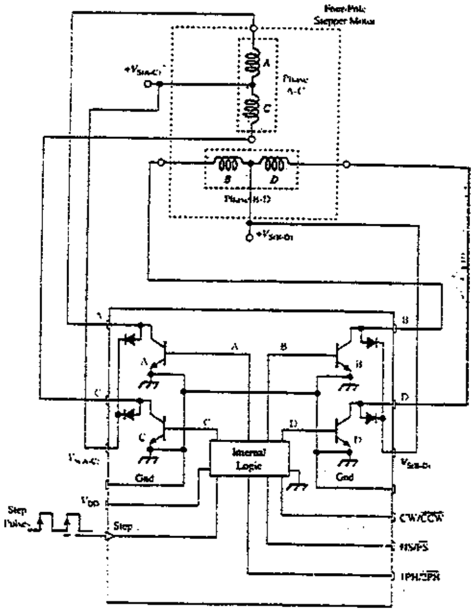

Fig.1 Hybrid step motor with the driving power circuit.

The basic expression relating terminal voltage and phase currents of electrical motors is given by [5]:

$$v_{ph} = R_{ph} i_{ph} + \frac{d\lambda_{ph}}{dt} \qquad (1)$$

where: v_{ph}, R_{ph}, i_{ph} and λ_{ph} are the stator voltage, winding resistance, and stator current and flux linkage of stator phase respectively. Of course the mechanical variable, rotor position θ, and rotor velocity ω, influence these electrical dynamic through the flux linkage derivative. The phase flux linkage is given by:

$$\lambda = L_{ph} i_{ph} \qquad (2)$$

From equs. (1) & (2) we obtain:

$$v_{ph} = R_{ph} i_{ph} + L_{ph} \frac{di_{ph}}{dt} + e_{ph} \qquad (3)$$

In HSM, as the rotor rotates, an emf e_{ph} is induced in the phase winding. The polarity of this induced voltage is such as to absorb power from the electrical source v_{ph} and its magnitude is proportional to the rotational speed ω.

$$e_{ph} = K_E \, \omega \qquad (4)$$

3.1. HSM Motor Dynamics.

The dynamic model of the HSM is a set of differential eqns. given by [6]:

$$\frac{di}{dt} = (L)^{-1}\left[v - ri - k\omega i\right] \qquad (5)$$

$$\frac{d\omega}{dt} = (J)^{-1}\left[B\omega + T_e - T_l\right] \qquad (6)$$

$$\frac{d\theta}{dt} = \omega \qquad (7)$$

3.2. Direct-Drive Robot Dynamic.

The dynamic model of the robot manipulators has been described in many publications[7-8]. The schematic structure of the single-link robot is shown in fig. 2. The payload is considered as a point mass *m*, which is located at the end of a massless link of length *L*. The input to the robot is the driving torque generated from the motor T_e, and the states of the system are given by the joint position q and velocity $q^{\cdot}$. The single-link robot arm dynamic eqn. is given by:

$$T_e = mL^2 q^{\cdot\cdot} + mgl \sin q \qquad (8)$$

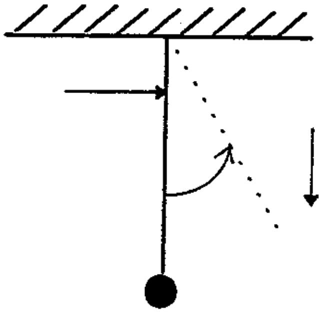

Fig. 2 Single-link robot arm.

4.Microstepping Operation.

We mentioned that the HSM has tow mode of excitation schemes, the single-phase and the tow-phase excitation that cause the rotor to move by one step-angle for each change in excitation. Combining the single-phase and two-phase excitations make it possible to achieve half-step rotations for each change of excitation. The procedure for half-stepping can be extended to subdivide the motor step-angle into very small steps called micro-steps. This require that the magnitudes of the phase currents be precisely controlled. Assuming the torque characteristics for a HSM to be sinusoidal, and the equilibrium position for i_A, excitation as $\theta = 0$, T_A and T_B with i_A, i_B respectively can be expressed as:

$$T_A = -K \, i_A \sin \theta \qquad (9)$$

$$T_B = K \, i_B \cos \theta \qquad (10)$$

Where K is the motor torque constant and the rotor position θ is measured in electrical degrees. When both phases are excited simultaneously with i_A, and i_B, the total torque developed is:

$$T_{AB} = K\,(-i_A \sin \theta + i_B \cos \theta) \quad (11)$$

To change the rotor angle θ by a micro-step angle μ, the two phase current are precisely controlled to two discrete levels such that:

$$i_A = I_R \ \sin\theta \qquad (12)$$

$$i_B = I_R \ \cos\theta \qquad (13)$$

Where I_R is the rated phase current. Therefore, from these equns,

$$T_{AB} = K\,(-\cos\mu \ \sin\theta + \sin\mu \ \cos\theta) = -K I_R \sin(\theta - \mu) \qquad (14)$$

To obtain very small stepping angles, the phase supply voltage, can be modulated. The modulation can be amplitude type or pulse-width modulation type (PWM).

5.The HSM Control System.

In this section we present and describe the prototype control system of the HSM. The HSM used in this system is RS type and its data is given in appendix A.The operation of a stepper motor requires the presence of the following elements:

1. A control unit: Usually a microprocessor based unit, which gives step and direction, signals to the drive unit card, the microprocessor kit used is 8088.
2. Drive unit card: This converts the signals from the control unit in to the required stepper motor sequence, it is RS type combatable with the HSM used.
3. Power supply : Giving the required voltage and current for the drive card.

Typical Stepper motor control system is shown in fig.3.

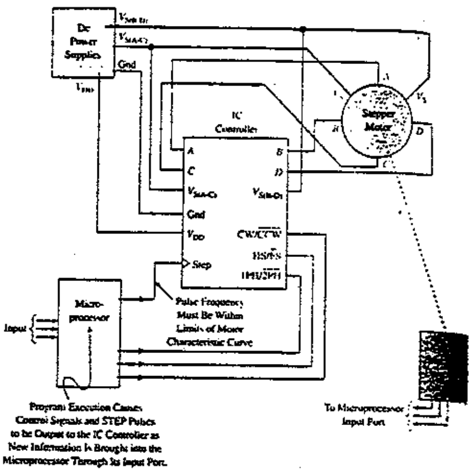

Fig. 3 The HSM control system.

5.1 Position Trajectory Control of HSM.

The control scheme of the trajectory tracking control HSM with the DDR is shown in fig. 4. The DDR system is commanded to move from initial position to a target position, following a desired trajectory profile. Generally, the objective is to design a trajectory controller for position tracking system with minimum tracking error in specific time.

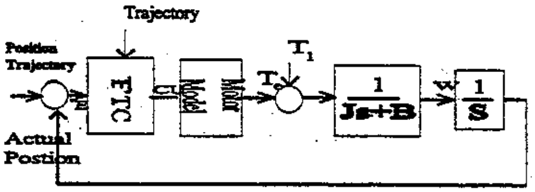

Fig. 4 The trajectory control scheme of the HSM.

The input to the trajectory controller is position error which represent the difference between the desired input trajectory profile and the actual output from the DDR system. The output from this controller is the control signal which represent the no of pulses per second or (frequency). This train of pulses is feeding the drive unit of the HSM to keep track of the desired profile. The tracking performance is given in the following section.

6.Simulation Rresults.

The first test , is done for the HSM with the DDR system implementing the FTC trajectory control scheme, the simulation results are shown in figs. 5&6. The simulation results are carried out using simulink The joint arm is commended to change smoothly from the initial position $\theta = 0$ to the target position $\theta = 90$ in 10 sec. following the desired sigmoidal trajectory. It is seen from the figures that the desired trajectory and actual output profile of the joint arm are very close, and the peak value of the error is 1.5 degree. The simulation results shown in figs. 5,and 6, are obtained according to inconsiderable disturbances in the DDR system.. It is shown that The tracking response of the DDR is matched with the desired trajectory, and the max. tracking error is drooped to less than .1 degree. The second test is done with appling the conventional PID controller. The simulation results are shown in figs. 7&8. It is evident that the tracking performance of the FTC trajectory controller is noticeably better than the PID.

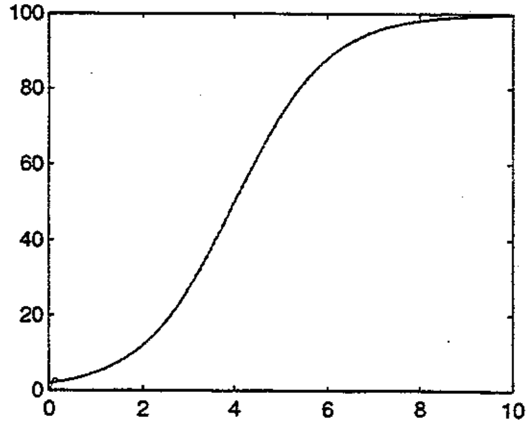

Fig. 5 The Tracking performance of the DDR system with FTC.

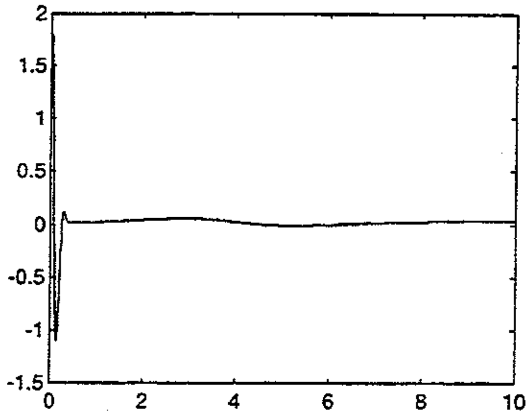

Fig. 6 Tracking error signal with FTC.

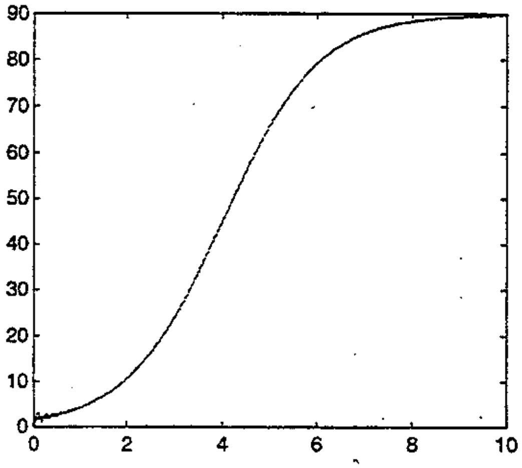

Fig.7 The tracking performance of the DDR system with PID controller.

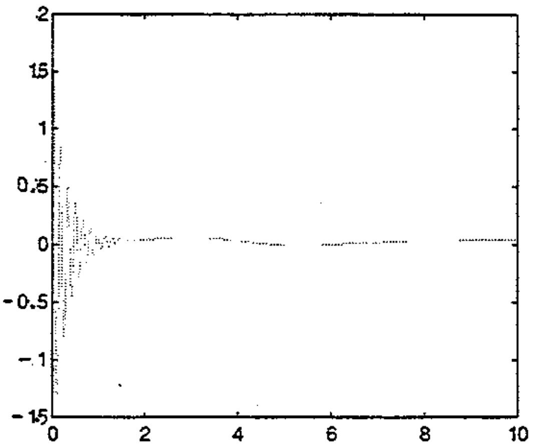

Fig. 8 The tracking error signal with PID controller.

7. Conclusion.

This paper introduses intelligent position tracking schemes for HSM coupled directly to single-link robot arm (DDR), These intelligent control schemes ulilize the fuzzy logic control technique. The performance of the position tracking system has good responce with the impelementation of the FTC scheme. The proposed control scheme can overcome of the uncertainty and the unconsiderable disturbances presented in the DDR system.

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Appendix (A)

The hybrid step motor used in this prototype system has the following specifications:

The RS stock number : Type 23 (440-442)
The rated voltage : 5.1 V
Rated current : 1 Amp
Winding resistance : 5 Ohm
Winding Inductance : 9 mH
Detent Torque : 30 mNm
Holding torque : 500 mNm
Step angle :1.8 degree
Step angle accuracy : 5%