Modelling and Control of 2-DOF Robotic Manipulator Using BLDC Motor

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Abstract*—*In this paper, a 2-DOF robotic manipulator is controlled to track motion of its end-effector in a plane using brushless DC motor as an actuator. Two brushless DC motor are used to actuate the each of two revolute joints of the 2-DOF robotic manipulator. To control the angular position of robotic arm fuzzy controller is used. To generate the Smooth trajectory for joint angle of robotic manipulator, cubic polynomial equation is used. The link lengths for two links and time for tracking is specified. It is shown that the end-effector of the manipulator reaches from initial to final co-ordinate , in specified time.

Keywords- BLDC, forward and inverse kinematic, end-effector

I. INTRODUCTION

High accuracy trajectory tracking is a very challenging topic in direct drive robot control.. This paper presents, the modelling and control of a 2 DOF(degree of a freedom) direct drive robot arm. Direct drive robot arm is mechanical arm in with high torque. Therefore, it does contain transmission mechanisms between motors and their load. Two brushless DC motor are used to actuate the each of two revolute joints of the 2-DOF robotic manipulator.

Recently, DC motors, stepper motors & single phase induction motors are being replaced by BLDC motors since industries application require more powerful actuators in small size. Elimination of brushes and commentator also solves the problem associated with contacts and gives improved reliability and enhance life. The BLDC motor has low inertia, large power to volume ration and low noise as compared with permanent magnet DC servo motor having the same output rating[2]-[4]. Therefore high performance BLDC motor drives are widely used for variable speed drive system in industrial application and to control of the robot arms and tracking application.

In this paper, forward and inverse kinematic of the 2-DOF robotics arm manipulator have been calculated using the trigonometry. The movement of object in a plane is analyzed using model developed. In the model initial and final co-ordinates (X, Y) of the object have been given to the inverse kinematic model which generates the angular displacement for trajectory generator. Trajectory generator generates the smooth trajectory to be controlled by fuzzy controller. Fuzzy controller controls the angular position joint of the robotic manipulator.

The organization of the paper is as follows: In sec: II, the mathematical modeling of BLDC is described. Then in sec: III, formulation of forward and inverse kinematic equation is shown. In sec: IV, overall simulation model is presented. Simulation results are presented in sec: V, and in last section, sec: VI, some conclusion remarks are given.

II. MATHEMATICAL MODEL OF BLDC

The analysis of BLDC is based upon on the following assumption for simplification:- [5]

1. The motor is not saturated.
2. The stator resistance of all the windings is equal and self and mutual inductance are constant and equal.
3. Power semiconductor devices in the inverter are ideal
4. Iron losses are negligible.

According to the assumptions mention above, fige-1 shows the overall system equivalent configuration of the three phases BLDC (it has three stator windings and permanent magnet on the rotor) hence the circuit equation of the three windings in phase variables are given as [6].

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + P \begin{bmatrix} L_a & L_{ba} & L_{ca} \\ L_{ba} & L_b & L_{cb} \\ L_{ca} & L_{cb} & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

$$L_a = L_b = L_c = L$$

$$L_{ab} = L_{bc} = L_{ca} = M$$

Hence

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + P \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (2)$$

$$i_a + i_b + i_c = o \quad (3)$$

Therefore,

$$Mi_a + Mi_b = -Mi_c \quad (4)$$

Hence,

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (5)$$

and the electromagnetic torque equation is

$$T_e = \left(e_a i_a + e_b i_b + e_c i_c\right) / w_r \quad (6)$$

The equation of motion is,

$$pw_r = \left(T_e - T_L - BW_r\right) / J \quad (7)$$

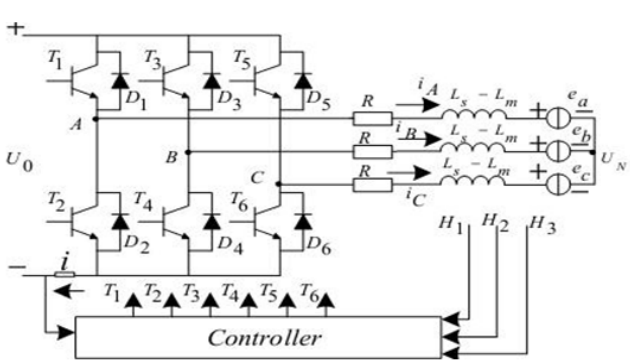


Fig. 1. Equivalent block diagram of BLDC.

III. FORMULATION OF FARWARD AND INVERSE KINEMATIC MODEL OF 2-DOF ROBOTIC MANIPULATOR [7]

In figure 2, 2-DOF robotic manipulator is shown.

A. forward kinematics equations:

$$X = L_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2) \quad (8)$$

$$Y = L_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2) \quad (9)$$

B. Inverse kinematics equations:

$$X^2 + Y^2 = L_1^2\left[\cos^2\theta_1 + \sin^2\theta_1\right] + 2L_1L_2\left[\cos\theta_1 \cos(\theta_1 + \theta_2) + \sin\theta_1 \sin(\theta_1 + \theta_2)\right]$$

$$X^2 + Y^2 = L_1^2 + L_2^2 + 2L_1L_2\cos\theta_2$$

$$\cos\theta_2 = \left(X^2 + Y^2 - L_1^2 - L_2^2\right) / 2L_1L_2$$

$$K_1 = L_1 + L_2\cos\theta_2$$

$$K_2 = L_2\sin\theta_2$$

$$\theta_1 = \tan^{-1}\left(Y/X\right) - \alpha \quad (10)$$

$$\theta_2 = \tan^{-1}\left(Y/X\right) - \tan^{-1}\left(k_2/k_1\right) \quad (11)$$

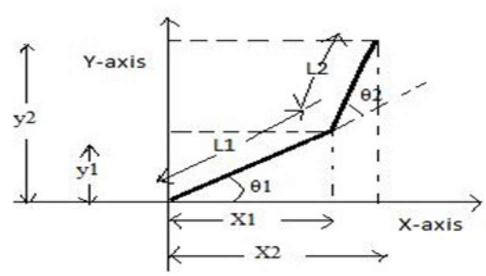


Fig 2. 2-DOF robotic manipulator.

Fuzzy controller:

Fuzzy logic is a new control approach with great potential for real time applications. The reference angular position from trajectory generator and actual joint angular position from feedback are taken as input to fuzzy system and output is reference speed for BLDC motor.

IV.OVERALL SIMULINK MODEL

In figure 3, overall Simulink model is shown.

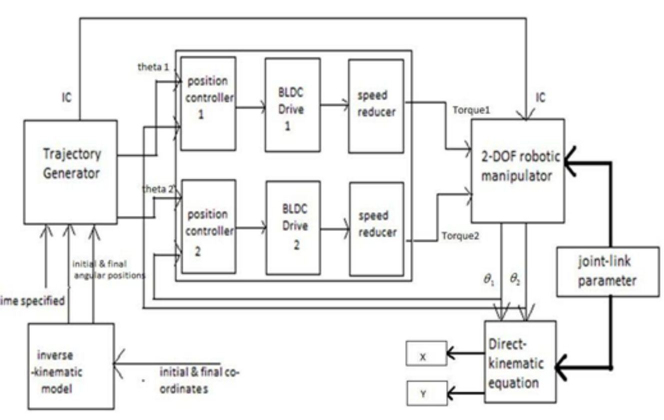


Fig.3. Overall Simulink model of 2-DOF robotic manipulator.

ISSN: 2278 – 7798

According to initial and final co-ordinate of the object, initial and final angular positions are calculated using inverse kinematic equations. The goal time is specified for trajectory generator. Trajectory generator generates the smooth trajectory using cubic polynomial. To interpolate the path connecting the initial to final joint position following cubic polynomial equation is used.

$$q(t) = q^s + 3/t^2(q^g + q^s)t^2 - 2/t^3(q^g - q^s)/t^3$$

Two fuzzy controllers are employed to control the angular position of two joints of the controller is reference speed for the BLDC drives. Two speed reducers are employed to reduce the speed, high speed shaft is connected with BLDC rotor and low speed shaft is connected with the joint of robotic manipulator. Direct kinematics equations generate X and Y coordinates of the end-effector.

V. Simulation Results

In this section we presented simulation results for 2-DOF robotic manipulator to track its motion in a plane.

The values of link1 L1=7m and link2 L2=5m. Initial and final co-ordinates of the end-effecter are chosen (9.7,1) & (12, 0) respectively. Final time t_{final}=1Sec is taken. And simulation results Are shown for time interval t = 1.5. In This time end-effector moves from Initial to final coordinates whose variation of X and Y,co-ordinates are shown in figure 4(a) & 4(b).

End-effector starts from initial co-ordinates(9.7, 1) and reaches to final co-ordinate(12,0) with in 1 sec, and stop moving after 1 Sec. During this time interval speed,torque variation is shown in figure 5(a),5(b) and 6(a),6(b).

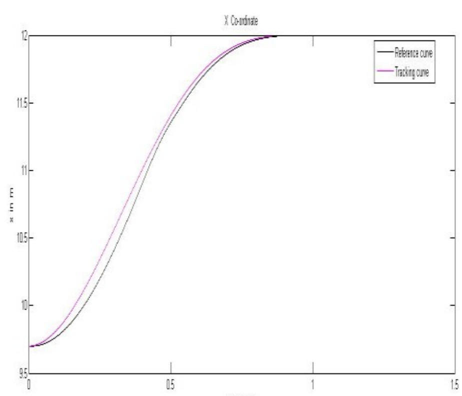


Fig.1 (a) X-co-ordinate variation of end-effector

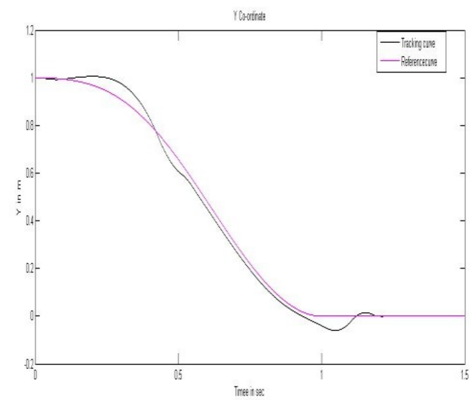


Fig.4 (b) Y-co-ordinate variation of end-effector

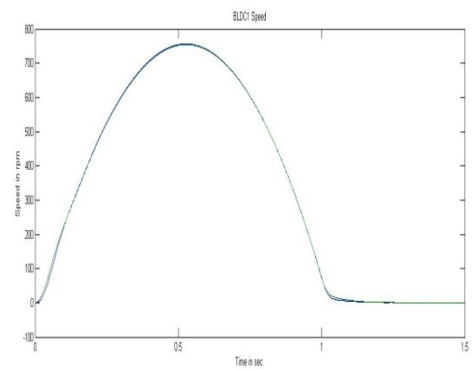
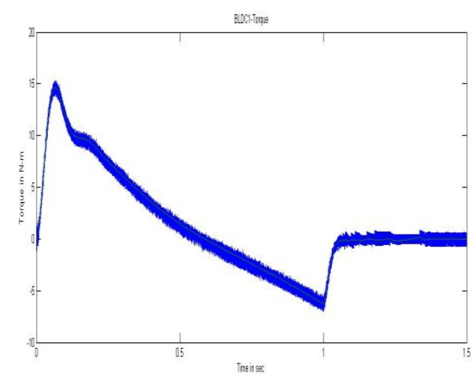


Fig.5 (a)



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g.5(b)

Fig.5 (a) Speed variation,(b) torque variation of BLDC1.

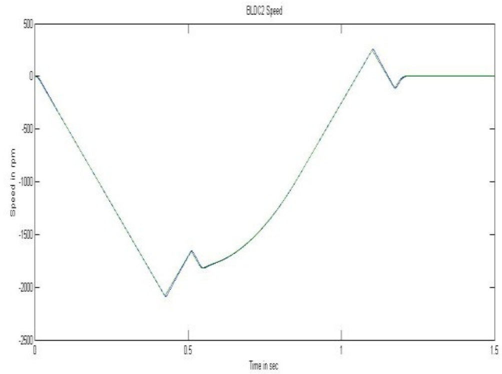

Fig. 6 (a)

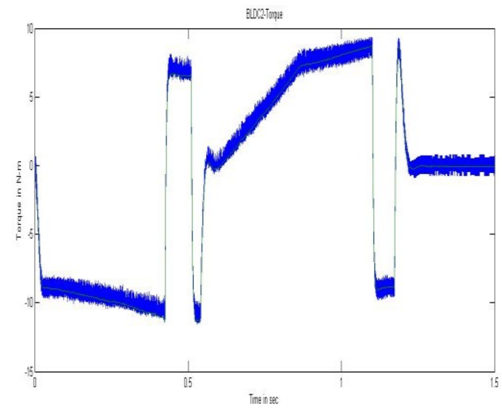

Fig.6 (b)
Fig.6 (a)speed variation, 6 (b) torque variation of BLDC2

VI. CONCLUSION

In this paper, the tracking of the object in a plane using 2-DOF robotic manipulator is presented. Tracking time, initial and final position co-ordinates are specified. A fuzzy controller is used to track the initial to final angular position of the joint generated by the trajectory generator. Simulations results show that controller control the end-effector effectively, and end-effector reaches from initial to final co-ordinates effectively.

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