Testing and control of delta robot using Using fifth order polynomial

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***Abstract*—Some of the widely used application of linear delta robot is as a pick and place robot or in 3d printers .After observing the working of the currently used delta robot we found that the surface finishing of the product manufactured using the 3d printer (delta robot) is not so smooth as per required finish. In our project, we are using 5th order polynomial trajectory of motion for controlling a delta robot. Our main aim is to achieve the smooth working and to reduce the infinite jerks which the robot exerts while performing the motion. Also, we are trying to reduce the cost of manufacturing of delta robot by using an low cost controller thus making it more economical to small scale industries and hobbyist**

Keywords—End milling, Optimization, Taguchi, Fuzzy logic.

I. INTRODUCTION

Trajectory planning is the most important part of controlling a robot. Every robot requires precise trajectory planning to carry-out any meaningful manipulation or transportation. The purpose of trajectory planning is to specify how the motor shaft will move from initial angle(x,y,z coordinates for end effector) to final angle (x_1,y_1,z_1). Various works in trajectory genearation methods are explained further. R. P. Paul and H. Zhong suggested using polynomials for trajectory generation. A. J. Koivo, L. Sciavicco and B. Siciliano proposed use of 3rd order trajectory generation method which uses four known parameters that is initial velocity, final velocity, initial position and final position for the calculation of coefficients which are used as trajectory for motor to follow. J.I. Quinones, X. Yang, Z. Feng, C Liu, and X. Ren have worked on generation of trajectory using trapezoidal velocity profile. But all the above methods suffer from infinite jerk which causes problems like motor wear . There are many solutions proposed to this problem some of which are use of fifth order polynomial proposed by J.J. craige which prevents infinite jerk spikes, Robert L. Williams II also proposed use of a single 6 order polynomial for continuous joint motion.

In this paper use of fifth order polynomial is chosen as it is easy to use and generates a continuous motion which is jerk free. This motion control method is applied to the delta robot and results are analysed for mechanical and theoretical accuracy.

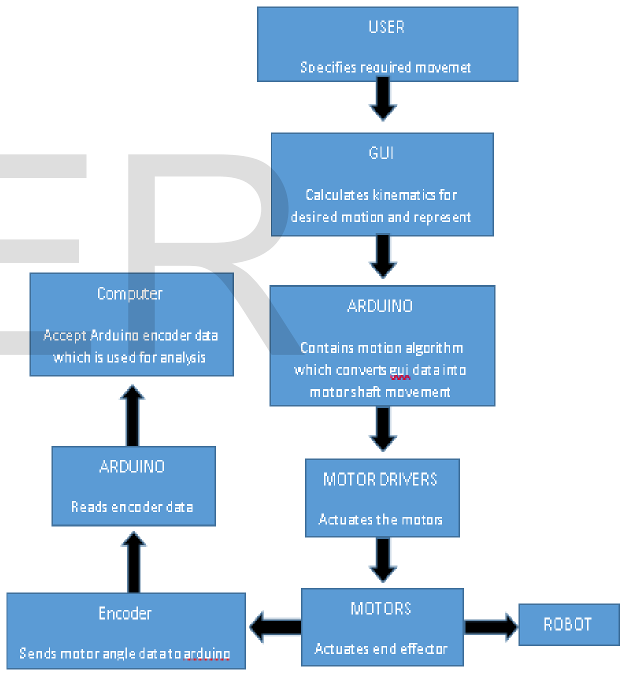

Fig. 1. Overall methodology of motion control

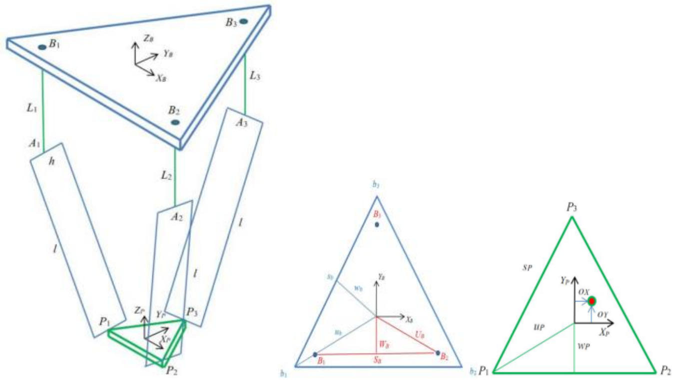

fig. 2. A. top view of robot frameB. top view of end effector

Inverse Pose Kinematics:

$$L_i = -z \pm \sqrt{z^2 -} \quad (1)$$

$$C_1 = x^2 + y^2 + z^2 + a^2 + b^2 + 2ax + 2by - l^2 \quad (2)$$

$$C_2 = x^2 + y^2 + z^2 + a^2 + b^2 - 2ax + 2by - l^2 \quad (3)$$

$$C_3 = x^2 + y^2 + z^2 + c^2 + 2cy - l^2 \quad (4)$$

$$a = S_B/2 - s_p/2 \quad (5)$$

$$b = W_b - w \quad (6)$$

$$c = u_p - U \quad (7)$$

$$W_B = \sqrt{3}/6 S_B,$$

$$U_B = \sqrt{3}/3 S_B,$$

$$w_b = \sqrt{3}/6 s_b,$$

$$u_b = \sqrt{3}/3 s_b,$$

$$w_p = \sqrt{3}/6 s_P,$$

$$u_p = \sqrt{3}/3 s_P$$

Fifth order polynomial trajectory generation :-
The section below details use of fifth order polynomial for trajectory generation.

$$(t) = a5t5 + a4t4 + a3t3 + a2t2 + a1t + a0 \quad (8)$$

$$\theta(t) = 5a5t4 + 4a4t3 + 3a3t2 + 2a2t + a1 \quad (9)$$

$$\theta(t) = 20a5t3 + 12a4t2 + 6a3t + 2a2 \quad (10)$$

$$\dddot{\theta}(t) = 60a5t2 + 24a4t + 6a3 \quad (22)$$

$$(0) = \theta_s, (t_f) = \theta_f (11)$$

$$\dot{\theta}(0) = \dot{\theta}_s, \dot{\theta}(t_f) = \dot{\theta}_f (12)$$

$$\ddot{\theta}(0) = \ddot{\theta}_s, \ddot{\theta}(t_f) = \ddot{\theta}_f (13)$$

$$a_0 = (14)$$

$$a_1 = \theta(15)$$

$$a_2 = \ddot{\theta}_s ?2 \quad (16)$$

$$a_3 = \frac{-20\theta_s - 20\theta_f + 12\theta_s t_f + 8\theta_f t_f + 3\ddot{\theta}_s t_f^2 - \ddot{\theta}_f t_f}{2t^3}$$

$$a_4 = \frac{30\theta_s - 30\theta_f + 16\theta_s t_f + 14\theta_f t_f + 3\ddot{\theta}_s t_f^2 - 2\ddot{\theta}_f t_f^2}{2t^4}$$

$$a_5 = \frac{-12\theta_s - 12\theta_f + 6\theta_s t_f + 6\theta_f t_f + \ddot{\theta}_s t_f^2 - \ddot{\theta}_f t_f 2}{2t^5}$$

Where $\theta s$and θf are initial and final input actuator positions such as motor shaft angle.

II. Result

Most of the results will be related to the experimental analysis of physical characteristics of the robot. The characteristics which are analyzed are: speed, accuracy, and motion.

Velocity Analysis:
Quantification of the maximum speed is done by analysis of the motion control algorithm. The timer interrupt which controls the motor has a period of 103 microseconds (a frequency of 9700Hz). Using equation rps= $\frac{frequency}{resolution}$ the maximum speed of the motor shafts are found to be 3.031rev/sec. Using equation L_i=rps.2πr the maximum line velocity is calculated to be 121 mm. Due to the complex nature of the robot's kinematics its maximum velocity is not constant throughout the horizontal work plane..

Accuracy Analysis Results:
Theoretical analysis is done for resolution of the robot . Matlab was used to calculate and measure the maximum errors in the x and y directions at all available locations in current usable work space. The results of the theoretical error analysis are shown in Figure 4 and Figure 5. Results show that there is a error of ±.014mm near the center of the workspace, and errors as low as ±.008 at the outer reaches of the workspace.

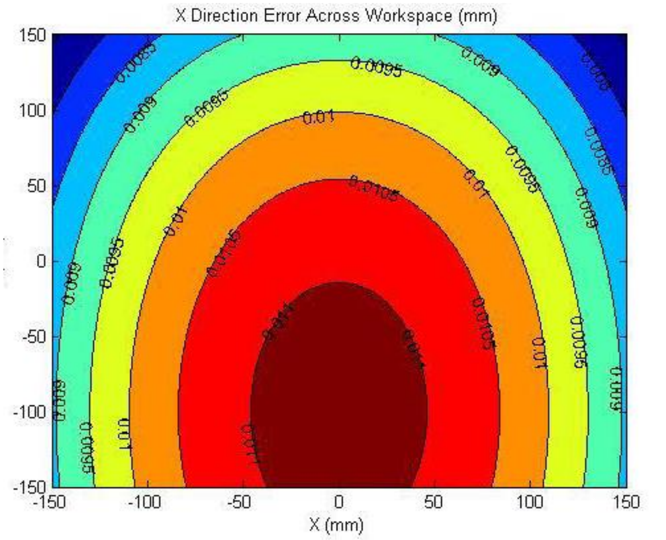

Figure 4: Maximum End Effector Error in X Direction at Locations Inside Horizontal Workspace (Errors in Units of $\pm mm$)

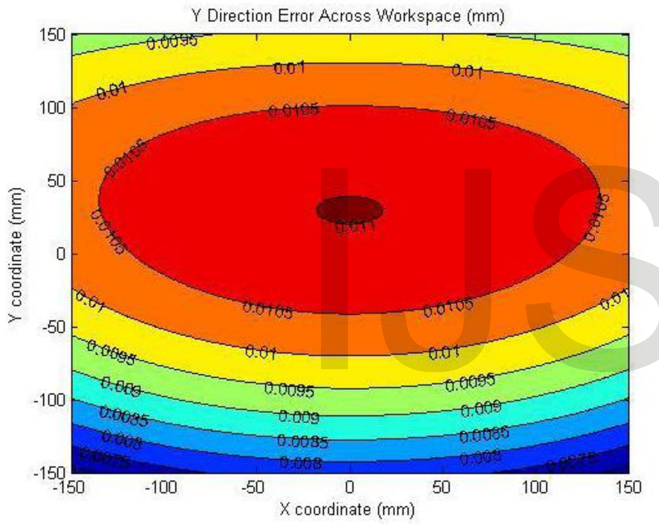

Figure 5: Maximum End Effector Error in Y Direction at Locations Inside Horizontal Workspace (Errors in Units of $\pm mm$)

Motion Analysis Results:

While analysing the motion of this control method, optical quadrature encoders are used. The data from encoder is gathered to plot the actual trajectories of respective motor shaft followed . These trajectories are plotted in Microsoft Excel and fitted with a 5th order polynomial trend line to quantify that they are indeed following 5th order trajectories. The encoder data is converted from encoder units to angular positions using equation angle=$\frac{360}{res}$ where Angle is the position of the motor shaft (in degrees), and res is the resolution of the encoder (2400} before plotting.

As a result of round off error inside the motion control algorithm when calculating time, there are small inaccuracies in the time domain which cause the *actual* movement duration to vary from the desired movement duration. This time difference is seen in the plots of joint data..

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