Optimal Trajectory Planning for the Design Optimization of the Robotic Arm

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***Abstract*—*This paper presents a synthetical approach for the design optimization and the trajectory of the robotic arm, angular velocity and acceleration of the robotic arm. The optimization of the robotic arm trajectory is a frequent design problem. Because of the complexity of this task in the past, many of the proposed approaches entailed only a suboptimal solution. The main problem in trajectory generation and tracking of robotic arm motions is to plan the trajectory and compute the required joint angles. Inverse kinematics modeling is usually adopted, though sometimes other approaches are needed due to the lack of reliability and accuracy of analytical methods. Due to that reason, previously, several authors have used evolutionary algorithms. Rana and Zalzala (1997) applied EA to the collision-free path planning of the robotic arm. In Garg & Kumar (2002), the formulation and application of Genetic Algorithm and Simulated Annealing for the determination of an optimal trajectory of a multiple robotic configuration is presented.*

***Keywords*—Genetic algorithm, inverse kinematics problem, modeling and control, optimal search, robotics, robotic arm trajectory.**

I. INTRODUCTION

One of the main problems in robotics research is the generation of trajectories that a robot must follow and the computation of the joint angles required to move the hand to the target positions. This is usually accomplished by the inverse kinematics of the robotic arm, which may be hard to derive or may not exist at all. For real applications, reliability, fast response and robustness of a Trajectory planning is one of the fundamental issues in the design and development of manipulators. The trajectory is normally determined to satisfy a certain criterion optimally. Optimal performance means different things to different people such as

minimum time, minimum kinetic energy, and obstacle avoidance. Optimization is normally performed in the presence of constraints. In addition to the dynamic system equations acting as constraints, there may be bounds on the inputs as well as constraints on some of the system constraints imposed by the manipulator itself and task constraints given by the task.

The problem is how to calculate feasible trajectories from a given path with simultaneous utilization of the maximal capabilities of the robots.

II. AN EXAMPLE OF DESIGN OPTIMIZATION PROBLEM

Considering a design problem and the design optimization was conducted on the 5-dof robotic arm. The link length of the robotic arm are fixed. The trajectory of the end effectors in the base coordinate system is defined as

$$X_{ef}(t) = 50 + 400\big(1 - Cos(t)\big),\ Y_{ef}(t) = -990 + 800(1 - Cos(t/2)),\ Z_{ef}(t) = 280 + 250(Cos(t/2) - 1)$$

, all with unit of mm. The corresponding velocity and acceleration profiles of the trajectory are defined in fig. The Euler angles for the end effectors are given as $[\mathrm{Cos}(t/180); 0,0]$ which implies the end effectors remains horizontal during the prescribed motion. The motion of the end effectors is illustrated in figure.

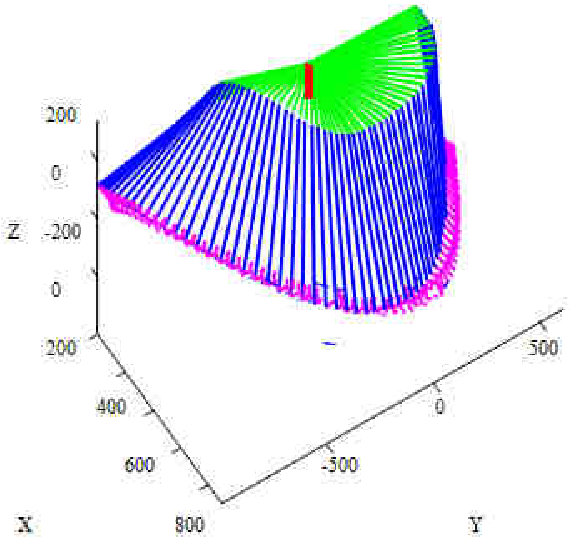

Fig.1: Trajectory of the robotic arm.

The joint angular velocities and accelerations are solved through the given Eq. (1.1)The solved results are depicted in Fig.2 and Fig.3. The joint angular velocity can be calculated with the Jacobian matrix.

$\dot{\theta} = J^{-1}V_{ef}$

(1.1)

Where $\dot{\theta}= [\dot{\theta}_1 , \dot{\theta}_2 , \dots \dots . \dot{\theta}_n]$ denotes an n-dimensional (n denotes the number of dof) vector of the joint angular velocities, J is the Jacobian of the robotic arm, and V_{ef} the velocity of the end-effectors.

$J = [J_1 , J_2 , \dots \dots J_n]$, $J_i = [Z_{i-1} \quad P_{i-1}]$

(1.2)

$Z_{i-1} = R_{i-1} [0 \quad 0 \quad 1]^T$,

$P_{i-1} = R_{i-1}\, q_{i-1} + p_i$ (1.3)

Where $q_{i-1} = [a_i Cos\theta_i , a_i Sin\theta_i , d_i]^T$ R_{i-1} denotes the rotation matrix from the reference coordinate system to the (i-1)th coordinate system. The local coordinates of the end-effector are defined as pn = [0; 0; 0]T. When the desired end-effector velocity V_{ef} is given, the joint angular velocity can be calculated.

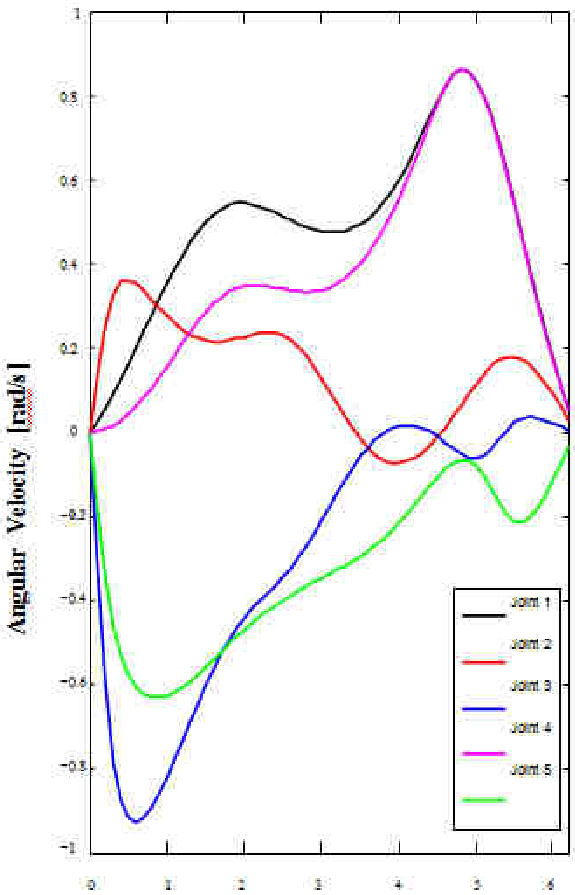

Fig.2: Angular velocities of the robotic arm.

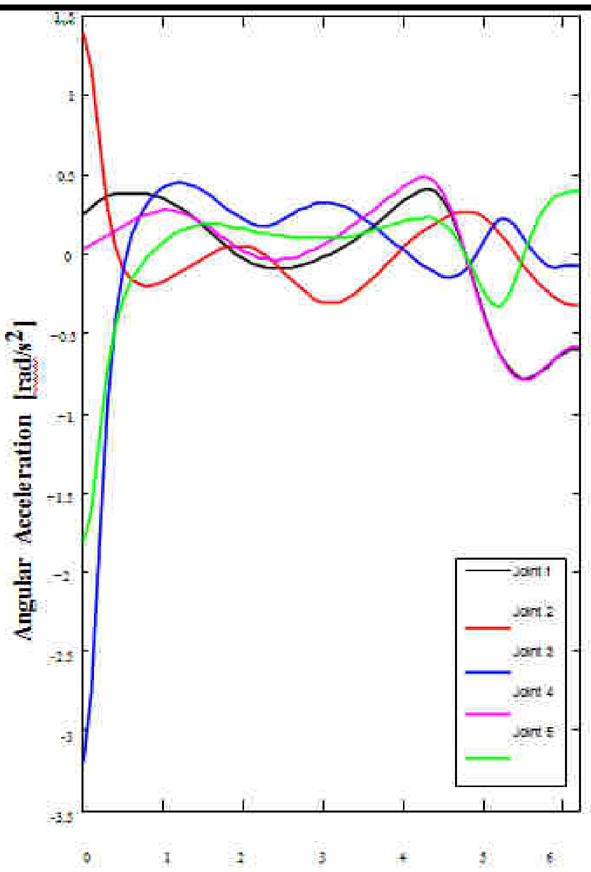

Fig.3: Angular accelerations of the robotic arm.

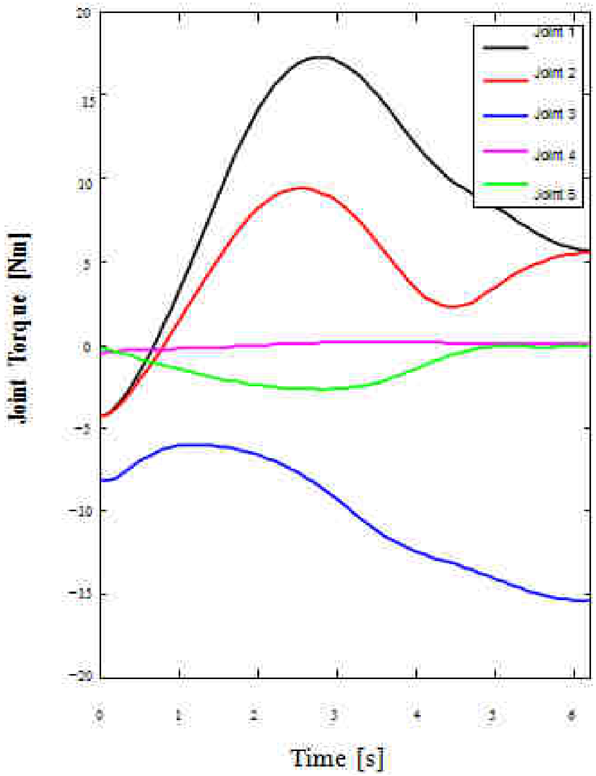

Fig.4: Joint torques of the robotic arm.

III. CONCLUSION

In the proposed robotic arm trajectory optimization, various design aspects have been considered, like operation-time minimization, robot rotation minimization, energy consumption minimization and combined optimization. Because the inverse kinematics task for a robot with many degrees of freedom is a complex problem, the genetic algorithm approach in combination with the robot simulation has been proposed. The results obtained have shown that such a design is able to provide very good results and it can achieve significant time savings, energy and wear and tear on the equipment. A review of the optimization techniques for the trajectory selection of robot is introduced. Kinematics approaches give interesting results but when comes to reality inertia and torque constraints make it difficult to implement. Dynamical approaches prove to be more realistic in terms of incorporating torque constraints and joints physical limits. Sometimes non-linearities and un-modeled dynamics are still problems in fulfilling the full dynamics model specially for flexible manipulators. It looks like the genetic algorithms are going to have more applications for the coming years. However, a GA may sometimes have difficulties to converge in an optimum solution.

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