양팔 로보트의 최적궤적 계획에 관한 연구

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A Study on optimal trajectory planning for a dual arm robot

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Abstract

This paper proposes an algorithm to find an optimal trajectory for unspecified paths of the tips of two arms of a dual arm robot. The effective handling a specified object of a dual arm robot closely depends on the effective collision avoidance between parts of robot and the object. For time optimal trajectory without collision, a graphical method is applied for a robot with two degree of freedom. The effectiveness of the proposed method is demonstrated by some simulation results.

1. Introduction

Coordinated motion contion of two arms of a dual arm robot has received increasing attention in recent years because of its potential application in assembly as well as handling large and heavy object beyond the capacity of a single manipulator. The major motivations for the use of the dual arm robot inculde its effectiveness to perform a specified job and its mechanical compactness that inherently results from its mechanical structure such as single controller and energy source.

This paper proposes an algorithm on the collision free time optimal trajectory generation under some constraints imposed on the robot.

In the sense that multiple robots are appropriate for many tasks requiring complex motions or dexterity, control strategy for them have similiar basis with that for multiple arm robot. Therefore, it is worth to look back on the researches on both of those fields. Wang(1) proposed a simple strategy for the attitute control and arm coordination of a maneuverable space robot with dual arms. Shahinpoor(2) suggested a near-optimal control algorithm for a highly nonlinear robot manipulator mode via a parameter sensitivity method and an optimal PD controller. Gilbert and Johnson(3) approached the collision-free optimal path planning problem by first expressing the collision avoidance. Shih(4) used an artificial potential field for path planning for two SCARA robot in the parameter space. Lee and Lee(5) delt with collision free motion planning of two robots by classifying path requirement situations.

Considerable research has been done to find time-optimal trajectory for prespecified paths of each robot. Nevertheless, less effort has been devoted to find it for unspecified paths. Generally explicit solution for nonlinear system is unattainable. One way to make the problem tractable is to linearize the system. However, this method can't avoid the inherent error caused by the drastic approximation in its linearization. This research focuses on finding time optimal trajectory for unspecified path of the tips of the both arms of the robot with graphical method. Inspite of its exhaustive search for the optimal trajectories, this method provides the exact solution for the given system.

2. Mathematical Model

The dynamics equation of the robot under consideration can be derived using Lagrange's equation which takes the form of

$$(J_i + m_i l_i^2)\ \ddot{\theta}_i + \frac{1}{2}\ m_i g\ l_i \sin\theta_i = T_i \quad \text{for} \quad i = 1, 2 \tag{1}$$

where J_i, m_i, and l_i represent the moment of inertia, mass and length of the i-th link of the robot. n is the number of degree of freedom of the system.

The vectors $\theta = (\theta_1, \theta_2)^T$ and $T = (\tau_1, \tau_2)^T$ are the joint angles and the applied actuator torques. The actuator's torque is constrained by the function of joint positions and velocities.

$$\tau_{i_{min}}(\theta, \dot{\theta}) \le \tau_i \le \tau_{i_{max}}(\theta, \dot{\theta}) \quad \text{for } i = 1, 2 \qquad (2)$$

where $\theta = (\theta_1, \theta_2)^T$. The feasible velocities and position are also bounded by

$$\dot{\theta}_{i_{min}} \le \dot{\theta}_i \le \dot{\theta}_{i_{max}} \qquad (3)$$

$$0 \le \theta_i \le \pi \qquad (4)$$

3. Time Optimal Trajectory Planning

3-1 Collision region between two arms

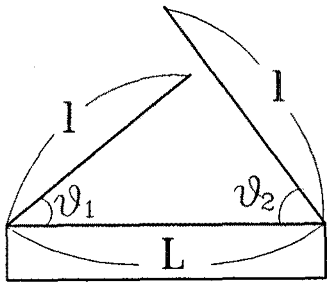

Fig. 1. The configuration of the robot under consideration

The collision region, $R_c(\theta_1,\theta_2)$ can be described as

$$R_c(\theta_1,\theta_2) = \left\{ (\theta_1,\theta_2) : l_1 \cos\theta_1 + l_2 \cos\theta_2 \ge L, \right.$$

$$\left. \tan^{-1}\frac{l\sin\theta_1}{L - l\cos\theta_1} \ge \theta_2,\ 0 < \theta_i \le \pi \text{ for } i = 1, 2 \right\}$$

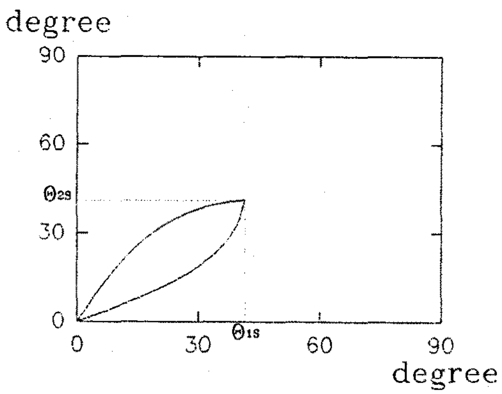

Fig. 2. Collision region for $l_1 = l_2 = 6$, and $L = 8$

3-2 Time-optimal trajectory

For a manipulator with multiple degree of freedom with actuator constraints, either control theory and exhaustive search approaches can be applied to find minimum time trajectory. However, the solution can be obtained by neither of them satisfactorily because of the nonlinearity of the system. For specified initial states and final states of the tips of the two arms, the time optimal trajectoty of each arm under the given constraints are shown on fig. 3. The time optimal trajectory of each tip for specified states can be obtained as shown in (6) by using maximum acceleration and deceleration.

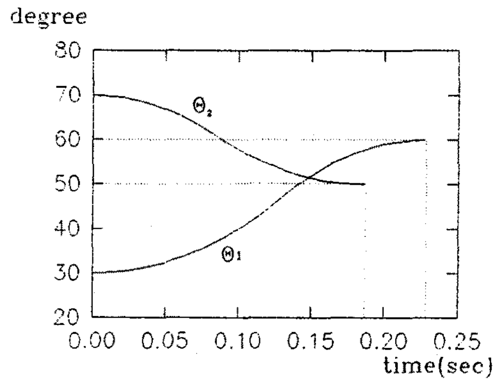

Fig. 3. Time optimal trajectory of the each arm of the robot

Let the traveling time of each arms be T_1 and T_2, then total traveling time of the robot is defined as

$$T = \max\{T_1, T_2\}$$

The problem can be defined to find the optimal trajectory and the corresponding time T for which the initial states of the tips of the arms reach their final states.

3-2-1 Simple case

For the robot under consideration, the positions of the tips of the robot are uniquely determined by the corresponding joint angles due to its inherent structure.

Therefore, in some where the movement direction of each arm need not to be changed for ts optimal movement, the algorithm suggested by Bien and Lee(7) can be directly applied to find the optimal trajectory. Here, the switching states of its acceleration and deceleration can be found by constructing the switching curves in the $\theta - \dot{\theta}$ phase plane.

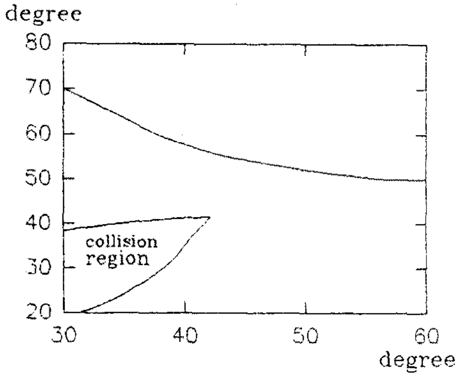

Fig. 4. Simple case with changing direction

3-2-2 General case

For specified start and goal state, the existence of time-optimal trajectories can be checked by inspection. The procedure to find them can be flowcharted as in fig. 5.

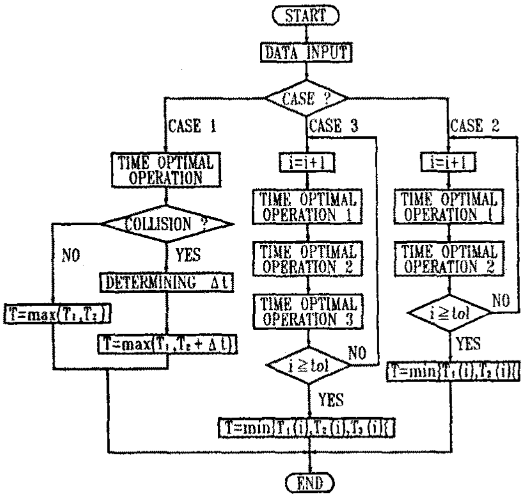

Fig. 5. Flowchart for finding time optimal trajectories

For case study, we assume that $\theta_1(t_0) \le \theta_2(t_0)$, $\theta_1(t_0) \le \theta_1(t_f)$, $\theta_2(t_0) \ge \theta_2(t_f)$ without loss of generality.

The situation is classified as three cases as shown belows.

Case ① : $\theta_{1s} \le \theta_{1f}$ and $\theta_{2f} \ge \theta_{2s}$

Case ② : $\theta_{1s} < \theta_{1f}$ and $\theta_{2s} > \theta_{2f}$

Case ③ : $\theta_{2s} > \theta_{2f}$ and $\theta_{1s} > \theta_{1f}$

These cases were performed in each step of the flowchart in fig. 5.

The results of case ① is shown in fig. 6-fig. 10.

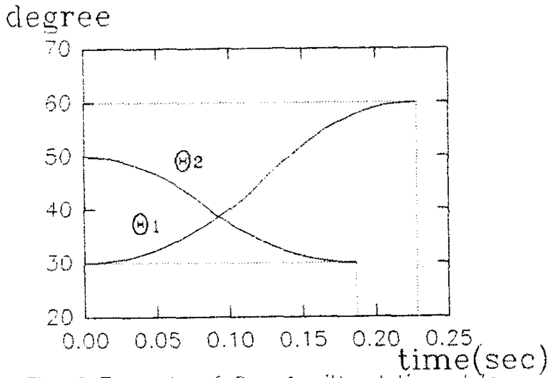

Fig. 6 Example of Case1 without time delay

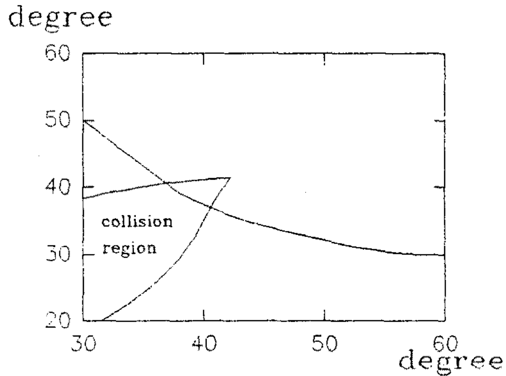

Fig. 7 Time optimal trajectory of Case 1 without collision free

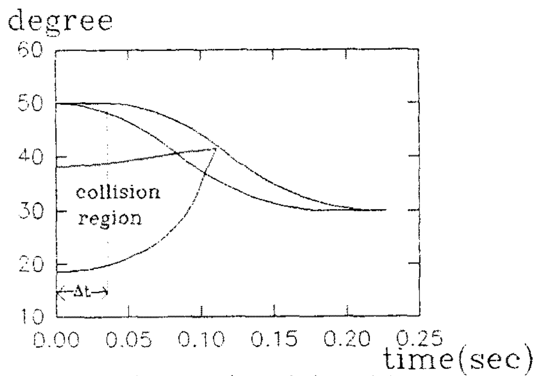

Fig. 8 Determining of time delay

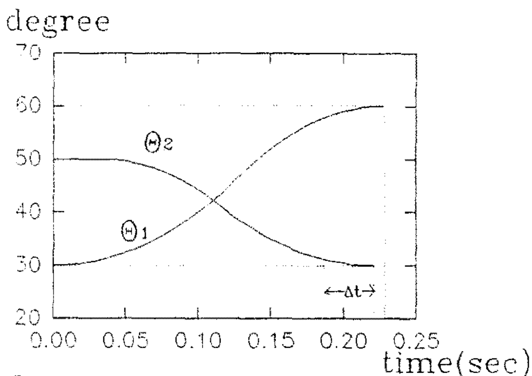

Fig. 9 Example of Case1 with time delay

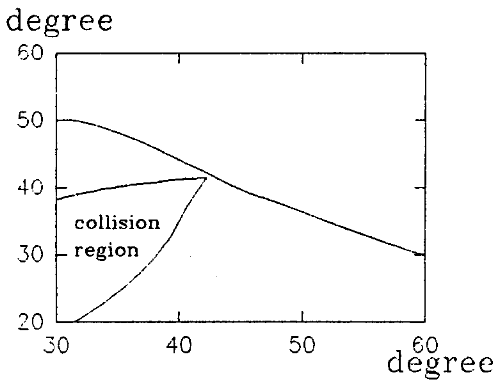

Fig. 10 Time optimal trajectory of case 1 with collision free

4. Concluding remarks

Generally, explicit solutions for nonlinear system are unattainable. The major advantage of the algorithm is that the exact solution can be found for given nonlinear system under some complex constraints. It should be notified that the proposed graphical survey can't avoid the exhaustive search for the solution.

Hopefully, the fast development of computer technology will make the proposed algorithm more attractive in future. The proposed algorithm can be modified by considering the safety region to ensure collision avoidance practically. The research on dual arm which has two degree of freedom for each arm is on the way.

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