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Trajectory Control of Multi-Degree of Freedom Rigid and Flexible Manipulators

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Abstract

The aim of this research paper is to provide a novel error dynamics based scheme for trajectory control of multi-degree of freedom *rigid* and *flexible* manipulators. Literature provides two methods to apply control on robot manipulators; viz. ‘independent *joint* control’ and ‘multivariable control’ [1]. The first method linearizes the dynamics by using high gear ratio(s) and all the *joints* of the robot are controlled independently by specifying different control gains on different *joints*. Any type of uncertainties whether internal or external are considered as disturbances. The second method makes use of robust control, adaptive control etc. This makes use of Computed-torque control (CTC)-type scheme described in literature. In the present work, control scheme based upon Coupled Error Dynamics [2] is applied. The difference between existing approaches and the approach presented here is that the system uncertainties are treated as either disturbances or modelled by selection of some suitable functions in the former while in the latter the system uncertainties are considered as part of the system itself. The CTC scheme usually described in literature makes use of the concept of ‘unit inertia’ [3],[4]. The control scheme described in present work, although uses CTC scheme, makes use of uncertainty in actual inertia of the system. The dynamics equation of a Two-Link Rigid robot [5] is reformulated as a coupled-error dynamics (CED) problem expressed by Equation (1).

$$[M_e]_{n\times n}\{\ddot{\theta}_e\}_{n\times 1} + ([K_v]_{n\times n} - [C_e]_{n\times n})\{\dot{\theta}_e\}_{n\times 1} + \left([K_p]_{n\times n} - [G_e]_{n\times n}\right)\{\theta_e\}_{n\times 1} = \{\tau_d\}_{n\times 1} \quad (1)$$

where, M_e = inertia matrix with uncertain terms; C_e = gyroscopic matrix with uncertain terms; G_e = gravity matrix with uncertain terms; τ_d = desired *joint* torque vector; K_p = proportional gain matrix; K_v = derivative gain matrix; θ_e is the *joint* error vector, n = number of *joints* and ‘.’ represents differentiation w.r.t. time. Equation (1) is non-linear and involves coupling between *joint* variables, and also exhibits time and configuration-dependent inertia. The remarkable thing about this equation is that it expresses the centrifugal and Coriolis’ torques vector present originally in the dynamics equation of Two-Link Rigid robot, as a linear function of *joint* error rate: $\{\dot{\theta}_e\}$. Further, the coefficients in Equation (1) are time-varying. The controller is designed based upon the concept of ‘modal analysis’ [6] and hence is termed as ‘Modal Controller’. This design approach helps in finding the proportional and derivative control gain matrices which contain non-diagonal terms also. Equation (2) describes the CED scheme for finding out the relationship between K_p and K_v gain matrices.

$$([K_v] - [C_e]) = \alpha_1 [M_e] + \alpha_2([K_p] - [G_e]) \quad (2)$$

where, α_1 and α_2 depend upon the Eigen values of the manipulator system. It can be seen that Equation (2) involves the presence of system parameters in defining the relationship between control gains. Fig. 1 and Fig. 2 show the comparison between CTC-based, CED-based and Robust controllers. A section on trajectory planning is also included in the paper, where the effect of choosing the type of trajectory on motion of the manipulator is shown. It is found that high order trajectory yields smooth motion as

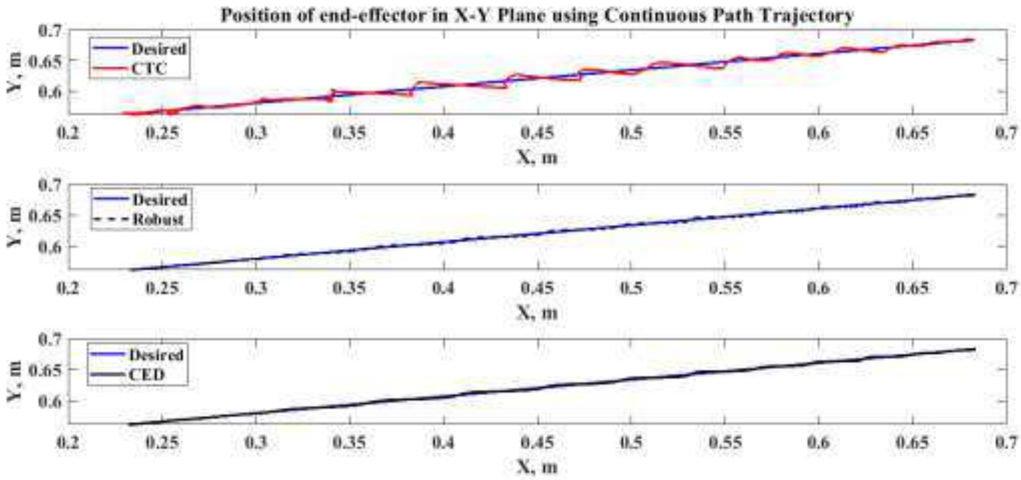

Fig. 1: Comparison of positions of end-effector of Two-Link Flexible manipulator [7] in X-Y Plane obeying Continuous path trajectory: obtained by using different controllers

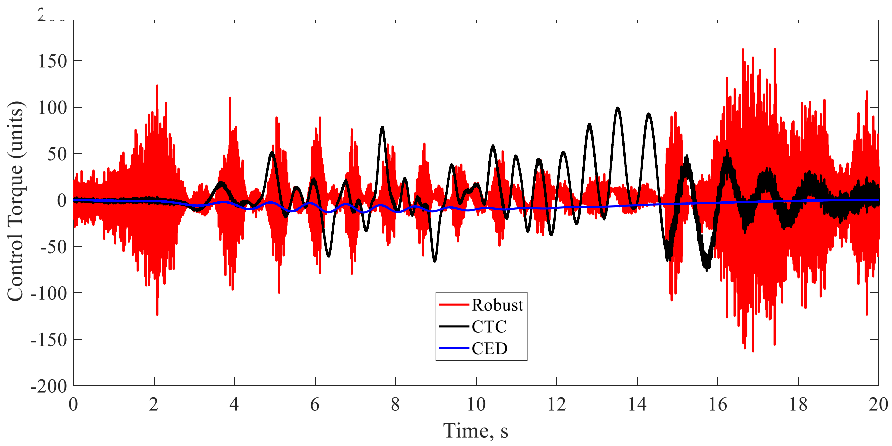

Fig. 2: Comparison between control torques provided by different controllers at Joint 2 of Two-Link Flexible manipulator [7] obeying Continuous path trajectory

jerks are eliminated but there is slight increase in torque requirements over low order trajectory. This high torque requirement may be eliminated by increasing the total time taken to traverse the path. Thus, trajectory plays a very important role in smooth path following by a robotic manipulator. Besides that, vibration of the *links* can be reduced significantly by proper planning of trajectory.

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