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An Adaptive Regulation Scheme for Manipulators

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Abstract

This paper presents an adaptive scheme for regulating the perturbed dynamics in the vicinity of a desired trajectory for robotic manipulators.
The scheme directly adjusts the control parameters to compensate destabilizing effects of the unknown, but slowly time varying parameters in the perturbation equation.

1. Introduction

Recently, a great deal of efforts has been made to increase the performance of robotic manipulation systems.
In particular, many researchers [1-7] aimed at maintaining good performance over a wide range of motions and payloads, and often used adaptive control methods to achieve this objective.
But, most of the existing methods needs to be improved in view of computational requirements and/or stability analysis of the overall adaptive systems.
In this paper, to improve some drawbacks in existing methods, a simple adaptive scheme based on Lyapunov's Direct Method is devised to regulate the uncertain perturbed dynamics about a given nominal trajectory while a nominal control is obtained from the Computed Torque Method.

2. Problem Statements

Dynamics of an n-jointed manipulator can be attained from the Lagrange-Euler equation of motion:

$$D(q;p)\ddot{q} + H(q,\dot{q};p) + G(q;p) = U \qquad (1)$$

Here, q denotes n-dimensional joint angle vector, U is n-dimensional control torque vector, and p denotes link parameter including payload. Equ.(1) can also be rewritten in state space form.

$$\dot{X} = f(X,U;p) \qquad ,X = (q',q')' \qquad (2)$$

If the nominal trajectory, control and parameter are denoted by Xn, Un and Pn respectively, then the following equations hold.

$$\dot{X}n = f(Xn,Un;Pn) \qquad (3)$$

$$dX = \nabla_x f_n dX + \nabla_u f_n dU + \nabla_p f_n dP \qquad (4)$$

where, $dX \triangleq X-Xn$, $dU \triangleq U-Un$, $dP \triangleq P-Pn$
For convenience, notations are chosen as below. [4]

$x \triangleq dX$, $u \triangleq dU$, $A(t) \triangleq \nabla_x f_n$, $B(t) \triangleq \nabla_u f_n$ and $d(t) = \nabla_p f_n dP$ Therefore, (4) becomes

$$\dot{x} = A(t)x + B(t)u + d(t) \quad (5)$$

In Equ.(5), the form of A(t),B(t) and d(t) are given by

$$A(t) = \begin{bmatrix} O_n & I_n \\ \multicolumn{2}{c}{\bar{A}(t)} \end{bmatrix} \begin{matrix} \}n \\ \}n \end{matrix}$$

$$B(t) = \begin{bmatrix} O_n \\ \bar{B}(t) \end{bmatrix} \begin{matrix} \}n \\ \}n \end{matrix}, \quad d(t) = \begin{bmatrix} 0 \\ \bar{d}(t) \end{bmatrix} \begin{matrix} \}n \\ \}n \end{matrix} \quad (6)$$

It is assumed that the system parameters $\bar{A}(t)$,$\bar{B}(t)$ and $\bar{d}(t)$ are unknown, but slowly time varying compared with control update speed. Also, it is assumed that the nominal control can be obtained from the Computed Torque Method and that state x is available through position encoders and speed tachometers.

Now, the problem is to determine a generating scheme of u(t) which drives x(t) to zero,i.e.,to develop an adaptive regulation scheme.

3. An Adaptive Regulator

The perturbed equ.(5) can be rewritten as follows.

$$\dot{x}(t)=Am\ x(t)+Bm\ u(t)+(A(t)-Am)x(t)$$
$$+(B(t)-Bm)u(t)+d(t) \quad (7)$$

where Am and Bm are predetermined contant matrices of the form.

$$Am = \begin{bmatrix} O_n & I_n \\ \multicolumn{2}{c}{\bar{K}} \end{bmatrix}, \quad Bm = \begin{bmatrix} O_n \\ I_n \end{bmatrix} \quad (8)$$

Here, $\bar{K}$ is chosen such that Am should be an asymptotically stable matrix of desired stabilizing property.

Now, to regulate the perturbed system (7), we propose the following adaptive regulator based on Lyapunov's Direct Method:

$$u(t) = -F(t)x(t)-G(t)u(t)-h(t)$$
or
$$u(t) = -(I+G(t))^{-1}(F(t)x(t)+h(t)) \quad (9)$$

where the adjustable matrices F(t) and G(t) of appropriate dimension and the adjustable vector h(t) are generated by the following adaptation laws:

$$\dot{F} = \Gamma_1 Bm'Zxx'$$
$$\dot{G} = \Gamma_2 Bm'Zxu' \quad (10)$$
$$\dot{h} = \Gamma_3 Bm'Zx$$

where Γ_1,$\Gamma_2$and Γ_3 , which are called the adaptation gain matrices, are chosen to be symmetric positive definite.

In Equ.(10), Z is a symmetric positive definite matrix satisfying

$$Am'Z + Z\ Am = -Q \quad (11)$$

for a given symmetric positive definite matrix Q.

The adaptation laws(10) can be easily shown if Lyapunov Function is chosen as follows.

$$V=\tfrac{1}{2}(x'Zx+Tr(\Delta F'\Gamma_1^{-1}\Delta F)+Tr(\Delta G'\Gamma_2^{-1}\Delta G)$$
$$+\Delta h'\Gamma_3^{-1}\Delta h) \quad (12)$$

where $\Delta F \triangleq F-F^*$,$\Delta G \triangleq G-G^*$ and $\Delta h \triangleq h-h^*$

Matching point(F^*,G^*,h^*) exists due to the condition(6).

Overall control system block diagram is given in Fig.1.

4. Computer Simulation Results

Computer simulation results for the Unimation PUMA600 series manipulator under maximum load(2.3Kg) and 10% estimation error in link mass, are presented to show the capability of the scheme.

Fig.2. and Fig.3. shows the position error of joint 3 of Constant PD Controller and Adaptive Controller respectively. We can see the good performance of proposed Adaptive Controller over Constant PD Controller.

5. Conclusion

The present adaptive scheme has simple structure over other existing ones and guarantees the stability of the overall system.

References

1. S.Dubowsky and D.T.Desforges,"The application of model reference adaptive control to robotic manipulators",ASME Trans.,J.of Dyn. Syst.Meas. and Cont.,Vol.101,Sep 1979, pp193-200
2. A.T.Koivo and T.H.Guo,"Adaptive Linear Controller for Robotic Manipulators",IEEE Trans. Auto.Cont., Vol.28,Feb. 1983,pp162-171
3. B.K.Kim and K.G.Shin,"Adaptive Control of Robotic Manipulators to Unpredictable Changes in their Dynamics", Proceedings of CDC IEEE 1983
4. M.J.Chung,"Adaptive control strategies for computer-controlled manipulators", Ph.D dissertation 1983, The Univ. of Michigan
5. M.Takegaki and S.Arimoto,"An adaptive trajectory control of manipulators",Int.J.Control,Vol.34,No.2, 1981,pp219-230
6. R.G.Walters and M.M.Bayoumi,"Application of a Self-Tuning Pole-Placement Regulator to an Industrial Manipulator",proceedings of cDC IEEE 1983
7. J.Lyou,"Decentralized Adaptive Stabilization of Large Scale Interconnected Linear Systems",Ph.D dissertation 1984, KAIST

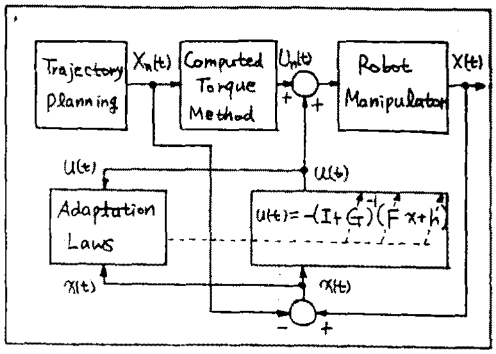

Fig.1 Overall Control System

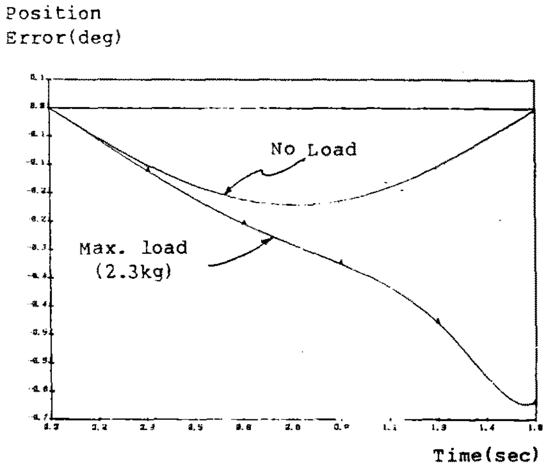

Fig. 2 Position error of Joint 3 in case of Constant PD Control

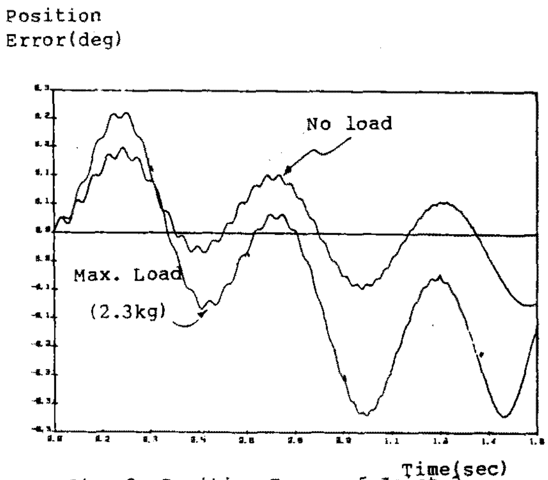

Fig. 3 Position Error of Joint 3 in case of Adaptive Control