Proceedings of the 13th
KACC, October 1998

Design of a DSP-Based Adaptive Controller for Real Time Dynamic Control of AM1 Robot

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Abstract

This paper describes the real-time implementation of an adaptive controller for the robotic manipulator. Digital signal processors(DSPs) are special purpose micro-processors that are particularly powerful for intensive numerical computations involving sums and products of variables. TMS320C50 chips are used in implementing real time adaptive control algorithms to provide an enhanced motion for robotic manipulators. In the proposed scheme, adaptation laws are derived from the improved Lyapunov second stability analysis based on the direct adaptive control theory. The adaptive controller consists of an adaptive feedforward controller and feedback controller. The proposed control scheme is simple in structure, fast in computation, and suitable for real-time control. Moreover, this scheme does not require any accurate dynamic modeling, nor values of manipulator parameters and payload. Performance of the adaptive controller is illustrated by simulation and experimental results for a assembling robot.

1. Introduction

Since the pioneering work of Dubowsky and Des-Forges[1], interest in adaptive control of robot manipulators has been growing steadily [1,2,3,4]. This growth is largely due to the fact that adaptive control theory is particularly well-suited to robotic manipulators whose dynamic model is highly complex and may contain unknown parameters. However, implementation of these algorithms generally involves intensive numerical computations.

Digital version of most advanced control algorithms can be defined as sums and products of measured variables, thus can naturally be implemented by DSP's. In addition, DSP's are as fast in computation as most 32-bit micro-processors and yet at a fraction of their prices[2],[6] These features make them a viable computational tool for digital implementation of advanced controllers.

In order to develop a digital servo controller one must carefully consider the effect of the sample and hold operation, the sampling frequency, the computational delay, and that of the quantization error on the stability of a closed-loop system[5,6,7,8,9]. Moreover, one must also consider the effect of disturbances on the transient variation of the tracking error as well as its steady-state value. This paper presents a new approach to the design of an adaptive control system using DSPs, TMS320C50, for robotic manipulators to achieve trajectory tracking in joint space and cartesian spaces.

This paper is organized as follows: in Section 2, the dynamic modeling and the adaptive control algorithm are derived. Adaptation laws are derived based on the model reference adaptive control theory using the improved Lyapunov second method. Section 3 represents simulation and experimental results obtained for a assembling robot. Finally, Section 4 discusses findings and draws some conclusions.

2. Adaptive Control Scheme

In order to consider payload in the manipulator dynamics, suppose that the manipulator end-effector is firmly grasping a payload represented by point mass ΔP. The nonlinear dynamic equation of robot manipulator with payload ΔP is given by

$$\Delta P\, J(q)^T [J(q)\, \ddot{q} + \dot{J}(q,\ \dot{q})\, \dot{q} + g] + D^*(q)\, \ddot{q} + N(q,\ \dot{q}) + G(q) = \tau(t) \qquad (1)$$

where $D^*(q)$ is the n×n symmetric positive-definite inertia matrix, $N(q,\ \dot{q})$ is the n×1 Coriolis and centrifugal torque vector, and $G(q)$ is the n×1 gravitational load vector. $J(q) = [\, \partial \lambda(q) / \partial q]$ is the n×n Jacobian matrix of the manipulator.

Equation (1) shows the explicitly effect of payload ΔP on the manipulator dynamics and it can be define as the implicit nonlinear dynamic equation

$$D(\Delta P,\ q,\ \dot{q})\ddot{q} + N(\Delta P,\ q,\ \dot{q})\dot{q} + G(\Delta P,\ q, \dot{q}) = \tau(t) \qquad (2)$$

In order to cope with changes in an operating point, gains are varied with the change in external working condition. This yields the adaptive control law

$$\tau(t) = [\, P_A(t)\, \ddot{q}_r(t)] + [\, P_B(t)\, \dot{q}_r(t) + P_C(t) q_r(t)] + [P_P(t) E(t) + P_V(t)\, \dot{E}(t)\,] \qquad (3)$$

where $P_A(t)$, $P_B(t)$, $P_C(t)$ are feed forward time-varying adaptive gains, and $P_P(t)$ and $P_V(t)$ are feedback adaptive gains. Fig. 1 represents the block diagram of adaptive control system for robotic manipulator.

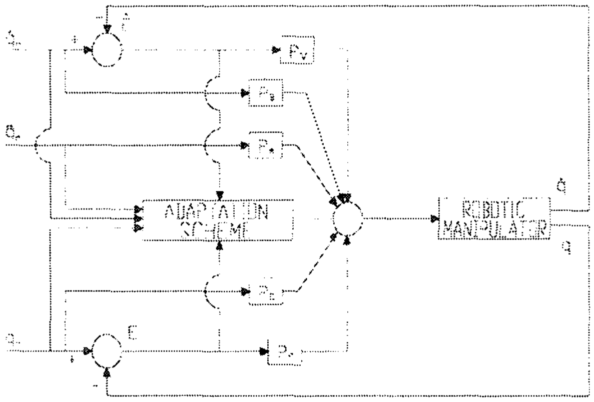

Fig. 1. The block diagram of adaptive control scheme for robotic manipulator.

On applying adaptive control law (2) to the nonlinear robot dynamic equation (2) the error differential equation can be obtained as

$$D\ddot{E}(t) + (N + P_V)\dot{E}(t) + (G + P_P) E(t) = (D - P_A)\ddot{q}_r(t) + (N - P_B)\dot{q}_r(t) + (G - P_C) q_r(t) \qquad (4)$$

Defining the 2n×1 position-velocity error vector $\varepsilon(t) = [E(t),\ \dot{E}(t)]^T$, equation (4) can be written in the state space form

$$\dot{\varepsilon}(t) = \begin{pmatrix} 0 & I_n \\ s_1 & s_2 \end{pmatrix} \varepsilon(t) + \begin{pmatrix} 0 \\ s_3 \end{pmatrix} q_r(t) + \begin{pmatrix} 0 \\ s_4 \end{pmatrix} \dot{q}_r(t) + \begin{pmatrix} 0 \\ s_5 \end{pmatrix} \ddot{q}_r(t) \qquad (5)$$

where
$s_1 = [D]^{-1}\, [G + P_P]$
$s_2 = [D]^{-1}\, [N + P_V]$
$s_3 = [D]^{-1}\, [G - P_C]$
$s_4 = [D]^{-1}\, [N - P_B]$
$s_5 = [D]^{-1}\, [D - P_A]$

The adaptation laws are now derived by ensuring the stability of error dynamics. To this end, let us define a scalar positive definite Lyapunov function as

$$\begin{aligned} L = \varepsilon^T R \varepsilon & + Tr\{[Q_1]^T K_1 [Q_1]\} \\ & + Tr\{[Q_2]^T K_2 [Q_2]\} \\ & + Tr\{[Q_3]^T K_3 [Q_3]\} \\ & + Tr\{[Q_4]^T K_4 [Q_4]\} \\ & + Tr\{[Q_5]^T K_5 [Q_5]\} \end{aligned} \tag{6}$$

where $Q_1 = w_1 - R_1 - w_1^*$, $Q_2 = w_2 - R_2 - w_2^*$, $Q_3 = w_3 - w_3^*$, $Q_4 = w_4 - w_4^*$and $Q_5 = w_5 - w_5^*$. R is the solution of the Lyapunov equation for the reference model, $K_1, \cdots, K_5$ are arbitrary symmetric positive definite constant n×n matrices, and matrices $w_1^*, \cdots, w_5^*$ are functions of time which will be specified later.

From the stability analysis by the Lyapunov second method, adaptive controller gains are obtained as

$$\begin{aligned} P_P(t) = & \; p_1 [P_{p1} E + P_{p2} \dot{E}][E]^T \\ & + p_2 \int_0^t [P_{p1} E + P_{p2} \dot{E}][E]^T dt \end{aligned} \tag{7-a}$$

$$\begin{aligned} P_V(t) = & \; v_1 [P_{v1} E + P_{v2} \dot{E}][\dot{E}]^T \\ & + v_2 \int_0^t [P_{v1} E + P_{v2} \dot{E}][\dot{E}]^T dt \end{aligned} \tag{7-b}$$

$$\begin{aligned} P_C(t) = & \; c_1 [P_{c1} E + P_{c2} \dot{E}][q_r]^T \\ & + c_2 \int_0^t [P_{c1} E + P_{c2} \dot{E}][q_r]^T dt \end{aligned} \tag{7-c}$$

$$\begin{aligned} P_B(t) = & \; b_1 [P_{b1} E + P_{b2} \dot{E}][\dot{q}_r]^T \\ & + b_2 \int_0^t [P_{b1} E + P_{b2} \dot{E}][\dot{q}_r]^T dt \end{aligned} \tag{7-d}$$

$$\begin{aligned} P_A(t) = & \; a_1 [P_{a1} E + P_{a2} \dot{E}][\ddot{q}_r]^T \\ & + a_2 \int_0^t [P_{a1} E + P_{a2} \dot{E}][\ddot{q}_r]^T dt \end{aligned} \tag{7-e}$$

where $[\lambda_1, p_{p1}, p_{v1}, p_{c1}, p_{b1}, p_{a1}]$and $[\lambda_2, p_{p2}, p_{v2}, p_{c2}, p_{b2}, p_{a2}]$are positive and nonnegative scalar adaptation gains.

3. Experiment and Results

This section represents DSPs-based control experimental results of the position and velocity control for a assembling robot with four joints and discusses the advantages of using DSPs for robotic motion control.

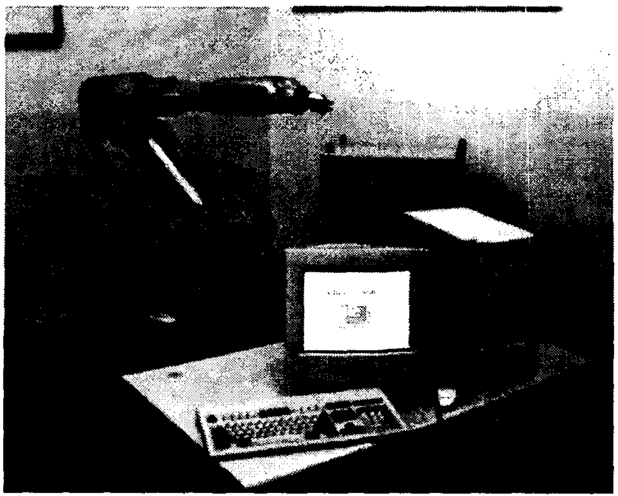

Fig. 2. Experimental set-up.

A set of experiments for the proposed adaptive controller was performed for the assembling robot. To implement the proposed adaptive controller, we used our own TMS320C50 assembler software developed. Also, a TMS320C50 emulator was used in experimental set-up as in Fig. 2. The TMS320C50 emulator is an application development tool which is based on the TI's TMS320C50 floating point DSP chip with an instruction cycle time 50ns. At each joint, a harmonic drive was used to transfer power from the motor, which has a resolver attached to its shaft for sensing angular velocity with a resolution of 8096 pulses/rev. The performance evaluation of proposed adaptive controller was performed in the joint space and cartesian space.

In the joint space, experiment was carried out to evaluate the position and velocity control performance of the four joints for variation of payloads. Fig. 3 shows the results of the position and velocity tracking control for the first joint with 3.0kg payload.

As can be seen from results, the DSP-based adaptive controller shows extremely good tracking performance even with the added external disturbance. Fig. 4 shows the experimental results of the position and velocity

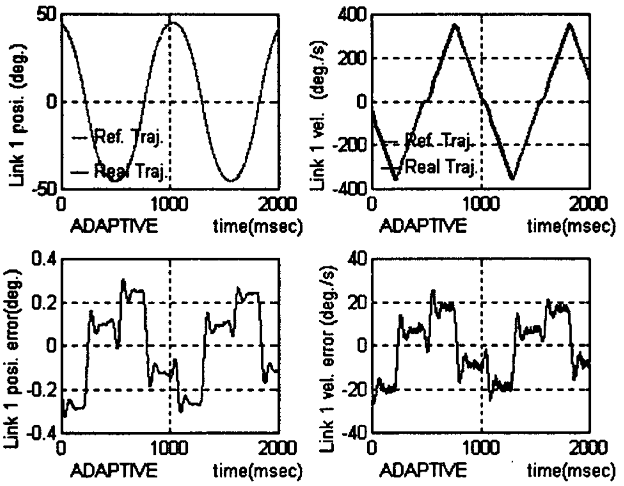

Fig. 3. Experimental results for the position and velocity tracking at the first joint with 3.0kg payload.

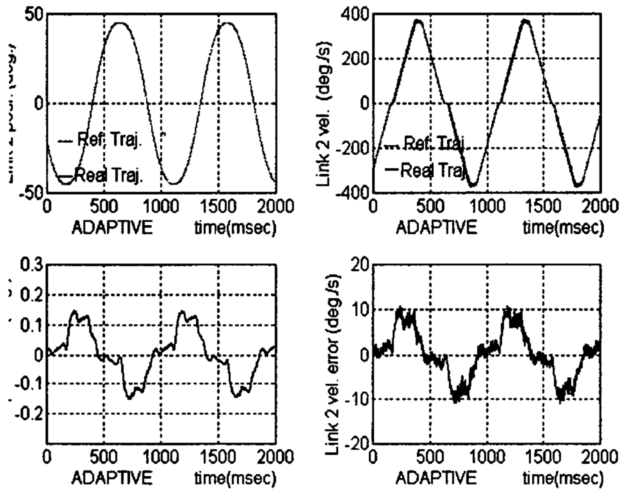

Fig. 4. Experimental results for the position and velocity tracking at the second joint with 3.0kg payload.

tracking performance for the second joint with 3.0 kg payload.

From experiment results, the proposed adaptive controller shows very good control performance in the test for trajectory tracking of the velocity and position in the joint space.

In the cartesian space, the adaptive controller was evaluated in a peg-in-hole task, and in a tracking task of B shaped reference trajectory. Fig. 5 represents the reference trajectory of assembling process and Fig. 6 represents the experimental results of adaptive controller for the B shaped reference trajectory with 3.0 kg payload and maximum velocity (3,000 rpm)

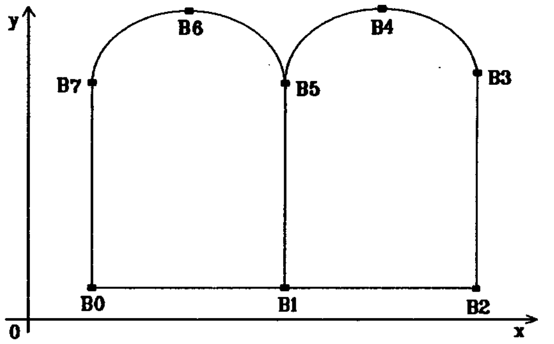

Fig. 5. The B shaped reference trajectory in the cartesian space.

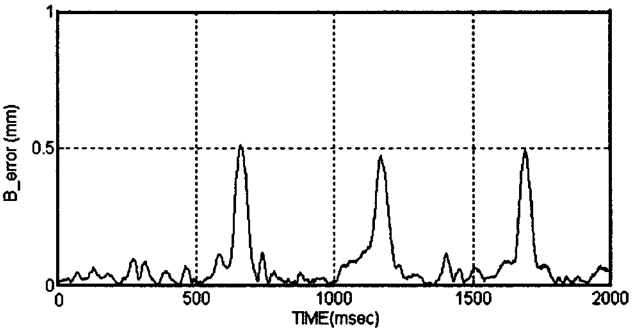

Fig. 6. Experimental result of the adaptive controller for tracking of B shaped reference trajectory with 3.0kg payload.

4. Conclusions

This paper has presented a new adaptive digital control scheme in this paper using the TMS320C50 chips for robotic manipulators. The adaptation laws are derived from the model reference adaptive theory using the improved direct Lyapunov method. The simulation and experimental results show that the proposed DSPs-adaptive controller is robust to the payload variation, inertia parameter uncertainty, and change of reference trajectory. This adaptive controller has been found to be suitable to the real-time control of robot system.

Control scheme uses only the information contained in the actual and reference trajectories which are directly available. Futhermore, the adaptation laws generate the controller gains by means of simple arithmetic operations. Hence, the calculation control action is extremely simple and fast. These features are suitable for implementation of on-line real time control for robotic manipulators with a high sampling rate, particularly when all physical parameters of the manipulator cannot be measured accurately and the mass of the payload can vary substantially.

ACKNOWLEDGE

This study was supported by Samsung Electronics Co., Ltd. as a part of G7 project supervised by Ministry of Commerce, Industry and Energy in korean government, ERC/Net Shape & Die Manufacturing at Pusan National University.

5. References

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