MICROPROCESSOR-BASED NOVEL VARIABLE STRUCTURE CONTROL FOR ROBOT MANIPULATOR

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MICROPROCESSOR-BASED NOVEL VARIABLE STRUCTURE CONTROL FOR ROBOT MANIPULATOR

土手康彦・篠島政明・吉村　斎

Yasuhiko DOTE, Masaaki SHINOJIMA and Hitoshi YOSHIMURA

Abstract

A new variable structure control scheme which consists of continuous adaptive gain feedback(PID and feedforward controls is developed to achieve accurate decoupled model following in a class of nonlinear time-varying system in the presence of disturbances, parameter variations and nonlinear dynamic interactions. The method is based on modified model following control with an improved sliding mode, which results in reducing the undesirable chattering remarkably. In addition an external torque observer with which the effects of external disturbances including parameter variations are roughly canceled is constructed. Then the developed method is practically applied to decoupled model follwing motion control for a two-degrees-of-freedom manipulator powered by PWM transistor converter-fed servo motors. The overall control strategies are implemented with both NEC PC−9801F(Intel 8086 Microprocessor) and TITMS32020(DSP). The DSP is a very attractive hardware for the realization of the robust and fast observer algorithm. It is confirmed by experiments that the position trajhctories are smooth and track the desired trajectories (output models) accurately. It is found that this new controller is simple and easy to be designed, performs extremely satisfactorily and is superior to the "conventional" PID controller for the robot manipulator.

1. Introduction

The accurate model following (tracking of desired trajectories) is the control challenge in the development of modern industrial robots and manipulators in a flexible manufacturing system environment.

In the overall system there exist many nonlinearities including differential efficiencies depending on direction of motion and stiction entering and leaving the locked state, variable torque loads, gear train backlashes, compliance and well-known nonlinearities in a converter-fed dc servo drive system. This can be described by nonlinear differential equations. Physically, the coupling terms represent gravitational torques which depend on positions of the arm, reaction torques due to accelerations and centrifugal torques. The significance of these interaction torques depends on the manipulator physical parameters and the load it carries. The existing control algorithms emphasize nonlinear compensations of the interactions. These nonlinear compensations are complex and costly to implement, since such schemes suffer from the requirement of a detailed model of the manipulator and load forecasting. They can not be implemented practically[10,12-14]. Model reference adaptive control (MRAC), which belongs to a class of active adaptive controls, is also applied to motion control of a manipulator. However, the global stability of MRAC systems in the case of uncertain nonlinear plants is problematic, especially, MRAC is sensitive to external disturbances and yields very slow dynamic characteristics.

The sliding mode control[1-7,9] yields robust control, however, the main drawback of this approach is that the control function is discontinuous and results in causing the undesirable chattering phenomena, although the method removes this chattering, it is too complicated to be actually implemented.[8]

This paper presents a methodology of a modified model following control with an improved sliding mode control in order to achieve decoupled tracking in a class of nonlinear systems (two-degrees-of-freedom manipulators) in the presence of disturbances, parameter variations and nonlinear dynamic interactions. In addition a robust and fast external force observer is constructed in order to cancel external disturbances roughly. The proposed control is based on a variable structure control scheme which consists of continuous adaptive gain feedback(PID) and feedforward controls with an external torque observer and a forced output model (convolution model). A desired model is generated in time series with a microprocessor. The feedforward path with the observer, which is different from [15], is added in order to cancel the external disturbances roughly and to make time responses faster. The feedback loop is for the purpose of obtaining the strong convergence properties of the error to the origin.

The proposed improved sliding mode control is continuous that not only guarantees that the error remains bounded, but also that it tends to an arbitrarily small neighborhood of the origin with a large rate of convergence.

Then the proposed method is applied to decoupled model following control for a two-degrees-of-freedom manipulator powered by PWM transiston converter-fed dc servomotors. The control strategy is implemented by an available microprocessor and a DSP.

This DSP plays an important role in constructing a robust and fast torque observer. The robustness of the obtained controller which results in accurate decoupled model following is confirmed experimentally. It is found that the system can be made robust by suitable choice of a forced model yielding very small steady-state and dynamic error and the controller can be easily designed since it requires less knowledge of the plant. This paper is organzed as follows. Firstly, the overall control system is illustrated. Then, experimental results are presented and discussed to compare with other presently available controllers such as a PID controller.

2. Novel Variable Structure Control Scheme

The overall control scheme is show in Fig. 1. The goal is then to find adaptive gain feedback and feedforward controls to nullify the erro e(t) as t→∞. In order to cancel the external disturbance roughly and to make time response faster, the next adaptive gain feedforward control is applied,

$$U_{ffi}(t)=K_{fDi}\phi_{Di}\dot{g}_i$$

$$\phi_{Di}=1+\frac{Sl_i}{|Sl_i|+\delta_{fi}}\cdot\frac{\dot{g}_i}{|\dot{g}_i|}$$

where δ_{fi} is a positive constant and P_i is a positive definite matrix and Sl_i is a sliding curve. If $\delta_{fi}=0$, then the control is called a sliding mode control. A block diagram showing the generation of K_{fDi} is illustrated in Fig. 2. This is a typical parameter adjusting mechanism except $S\Delta$ [16)]

$$S\Delta=Sl_i-\phi\ sat(\frac{Sl_i}{\phi})$$

where ϕ is a positive constant. Fig. 3. shows the relation of $S\Delta$ versus Sl_i.

Next an adaptive gain feedback control (PID) (extended sliding mode control) u_{fbi} is applied in order to stabilize the overall system asymptotically.

$$U_{fbi}=K_{VPi}|e_i|+K_{VIi}\int|e_i|dt$$

$$K_{VPi}=\frac{Sl_i}{|Sl_i|+\delta_{bi}}\cdot K_{Pi}$$

$$K_{VIi}=(1+\frac{|Sl_i|}{|Sl_i|+\delta_{bi}})\frac{Sl_i}{|Sl_i|}\cdot K_{Ii}$$

where δ_{bi}, K_{Pi} and K_{Ii} are positive constant. Fig. 4. shows the relation of K_{VPi} and K_{VIi} versus Sl_i. Near the sliding curve, an integral controller dominates.

The design procedure for the controller as follows.

1) Determine a Liapunov function $V_i(e_i)$, then evaluate a sliding curve,

$$sl_i=b_{oi}^{T}P_i\,[e1i,\ e2i]^{T}$$

2) Calculate the controls, *uffi* and *Ufbi*. The convergence of the error between the outputs of the model and the control object to the orjgin is proved in [15] and [16].

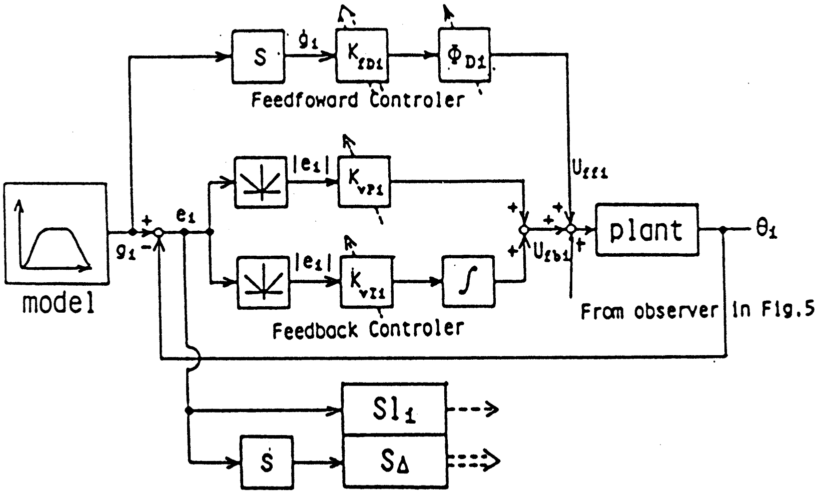


Fig. 1. Control scheme

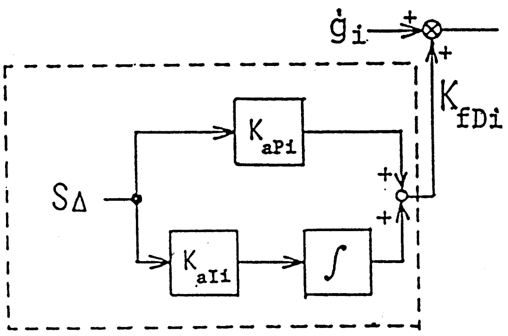


Fig. 2. Gain adaptive mechanism for K_{fdi}

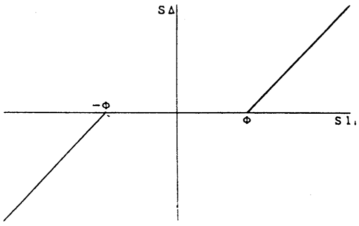


Fig. 3. Function SΔ of Sl_i

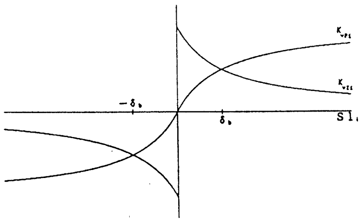


Fig. 4. K_{VIi} versus Sl_i

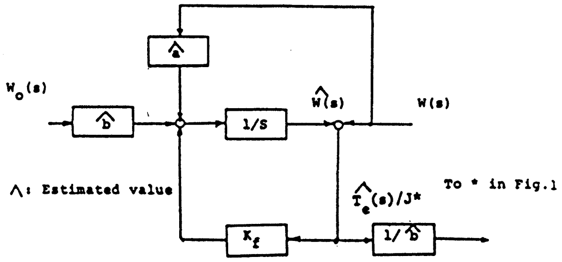


Fig. 5. External torque observer

3. Disturbance Cancellation With Observer

As the recent robot manipulator is required to have mode quich and precise response, the fast servo system and low ratio gear (sometimes direct drive system) tend to be adopted in each joint motion control system. In such a case, coupled force disturbances among each joint become significant.

In general sliding mode control is sensitive to persistent disturbaces resulting in chattering. Therefore in order to cancel the effect of disturbances roughly, a robust and fast torque observer whose derivation is based on well-known zeroing techniques, is constructed. A DC servodrive system is modeled as follows.

$$\dot{\omega} = -a^*\omega + b^* u_i - \frac{Te}{J^*}$$

where

$$a^* = -\left(\frac{B^*}{J^*} + \frac{K_t^* K_b^*}{J^* R_a^*}\right),\ b^* = \frac{K_t^* K^*}{J^* R_a^*}$$

u_i; servo amp input, J^*; inertia, K_b^*; counter e. m. f coefficient

K^*; servo amp gain, ω; angular velocity, K_t^*; torque constant

B^*; viscous friction coefficient R_a^*; armature resistance

ω_0; reference motor speed, T_e; total sum of coupled inertia force, centrifugal force, corioliv force, friction, viscosity, payload, gravity and stray force

$*$; nominal value

Therefore

$$\frac{Te}{J^*}(s) = -s\omega(s) - a^*\omega(s) + b^* u_i(s)$$

The following observer is constructed.

$$\frac{Te}{J}(s) = \frac{-s\omega(s) - \hat{a}\omega(s) + \hat{b}u_i(s)}{s+K_f}$$

where, $1/s+K_f$ is a filter(observer). This shows in Fig. 5. The band width of the filter should be wider than that of the external signal $Te(s)/J^*$. Otherwise, a stability problem arises. Thus the estimated value $\hat{T}e(s)/J^*$, $1/\hat{b}$ is fed into $*$ in Fig. 4. The combination of the proposed control scheme and the observer yields a robust control for even a direct drive robot manipulator. This observer also takes care of the effect of parameter variations.

since

$$\frac{Te}{J^*}(s)+\Delta a\omega(s)-\Delta bu_i(s)=-s\omega(s)+b^*\omega(s)+b^*u_i(s)$$

where

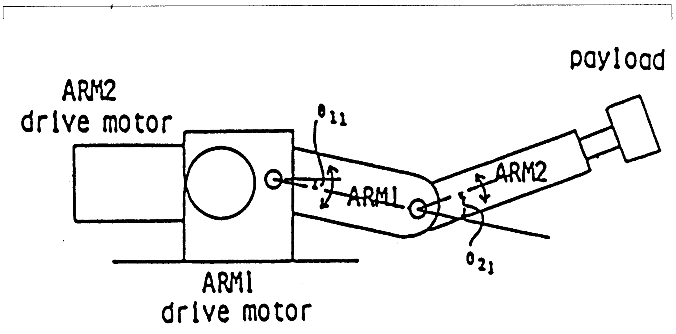
$\Delta a=a^*-\hat{a}$ and $\Delta b=b^*-\hat{b}$

This observer estimates the external distubances due to parameter variations. The observer can be easily realized by a fast DSP.

4. Description Of Control System

The proposed method was practically applied to decoupled tracking control for a two-degrees-of-freedom manipulator shown in Fig. 6. The heart or the system is a PC−9801(NEC) Microprocessor, which is based on the Intel 8086. The system includes a keyboard input device, a CRT display, a disket memory and its driver and a printer which have been used for program development and for storing and displaying the measured values. A Twelve bit D/A converter provides sufficient accuracy for this control purpose. Programs are written in assembly language. For a sensor an encoder is used (0.72deg/puls). A PWM transistor converter-fed dc servomotor is utilized to power a manipulator. Hardware details are shown in Fig. 7. The program has several modes of operation including 1) a data entry mode which the user can change program parameter (back ground) 2) a display mod where the measured and stored values are displayed on CRT and are printed out (back ground) 3) an automatic control mode where an improved sliding mode control is performed and the measured variables are stored (fore ground). The microprocessor finishes the complete set of computations to control a manipulator every 1.6ms (sampling time) and simply waits for the next cycle. Thus the ideal infinite switching frequency is limited by the microprocessor speed. Controller parameter are as follows.

The components which form the overall digital controller contiguration are shown in Fig.



DC servo motor with reduction gear ratio 1/50

Arm drive gear ratio 1/4

Fig. 6. Configuration of Robot manipulator

8. This DSP(TMS32020) development system consists of a NEC 9801 microprocessor (Intel 8086) and a digital interface board, a TMS32020 and D/A, D/D interface boards. In operation DSP programs are downloaded to the TMS32020 from the PC−9801 for excution. The TMS32020 has the initialization program and date memory areas. Each block of data is transfered from the host computer to the DSP. Experimental data are brought from the TMS32020 to the PC−9801, then they can be displayed on the CRT or on the printer. The program for checking memory maps is available.

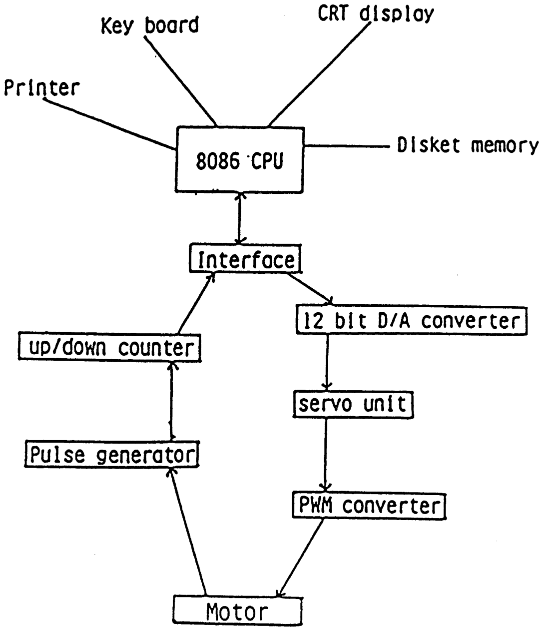


Fig. 7. Hardware details

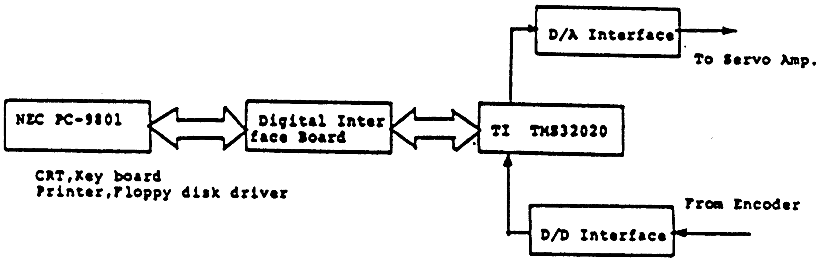


Fig. 8. Configuration of DSP Controller

5. Experimental Results

System time responses were obtained from actual measurements and stored in the computer, displayed on the CRT and printed out. Fig. 9. through Fig. 12. show the time responses of the manipulator positions for the proposed control methodology. Noninteracting smooth controls were achived. This controller is robust. This modified model following control with an improved sliding mode method is an effective means of decoupled tracking controls for a two-degrees-of-freedom manipulator shown in Fig. 13.

Performance of the proposed controller and PI controller is compared in Fig. 14. This PI controller may not be optimum, however, it is a tedious procedure to find the optimal PI controller parameters. Even the tuned PI controller can be easily detuned for system parameter variations which often occur in general system. The proposed controller is more robust and easier to be designed than the PI controller. Fig. 15 shows the results for the DSP controller.

Actually, a servo amplifier includes minor current and speed feed back loops, which partly and roughly decouple and linerize this nonlinear system. This reduces the effect of all kinds of external disturb-

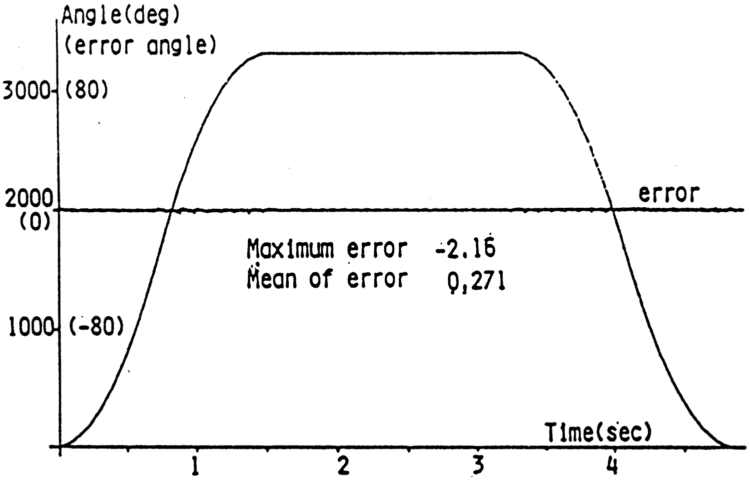


Fig. 9. Time response of motor angle

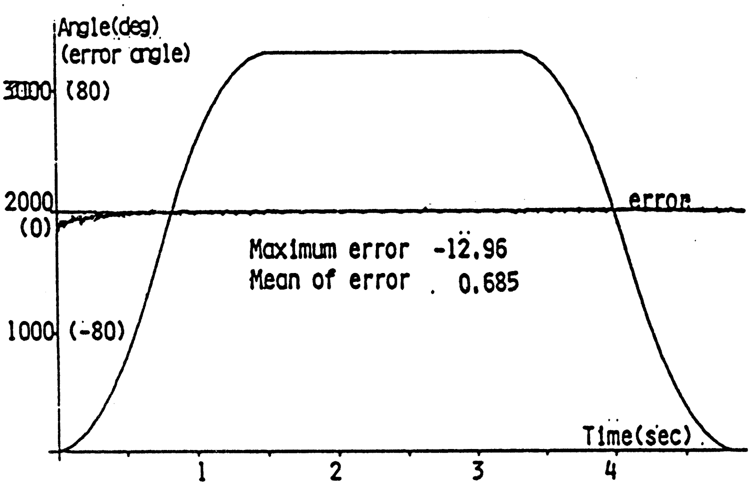


Fig. 10. Time response for persistent disturbance

ances. (by the current feed back loop).

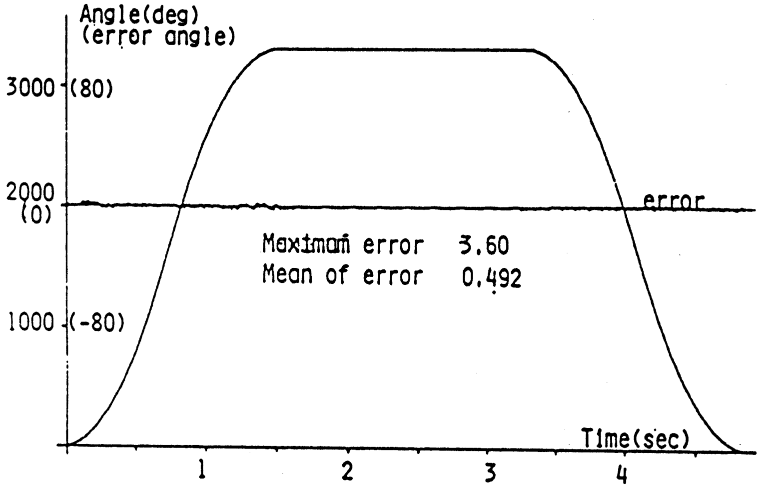


Fig. 11. Time response for changed payload (Proposed control method)

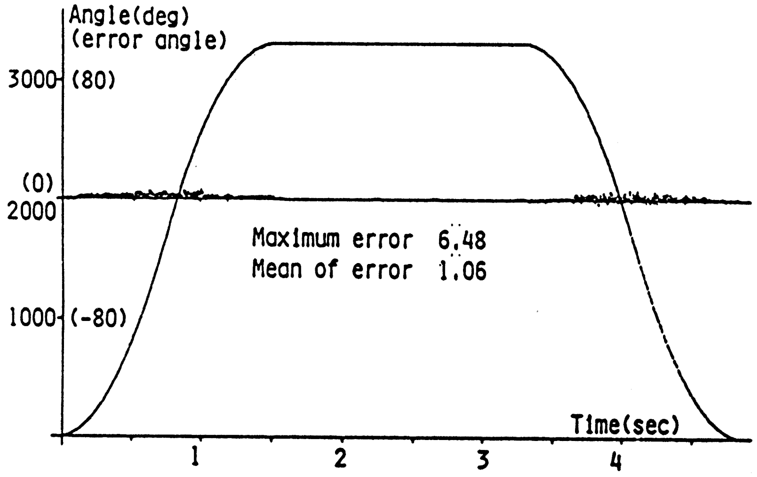


Fig. 12. Time response for changed payload (Conventional sliding mode control)

6. Conclusion

The synthesis of a practical controller for a two-degrees-of-freedom manipulator using a modified model following control with an improved sliding mode has been described in this paper. The problem considered was to find a robust continuous adaptive gain feedback(PID) and feedforward controller with an observer so that the output positions are satisfactorily regulated, tracked and decoupled. It is found that the new controller obtained, is simple and easy to be designed, performs extremely satisfactorily and is superior to the "conventional" available controller for the manipulator. Lastly, it is noted that the recent and rapid development of power electronics and microelectronics technology plays an important role in realizing the proposed control strategy.

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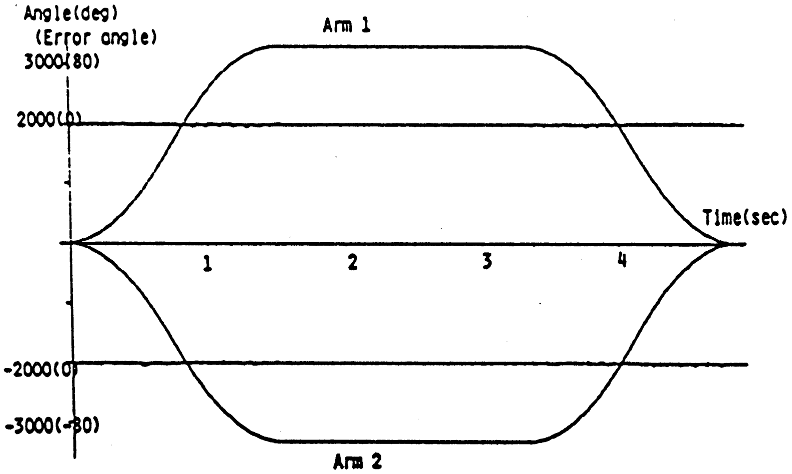

Fig. 13. Time responses of Arm 1 and Arm 2

Electronics Engr. Dept., Muroran Inst. of Tech. for their building all hardwares used here for experiment and the Horyu Robotics Co. Ltd. for their financial support.

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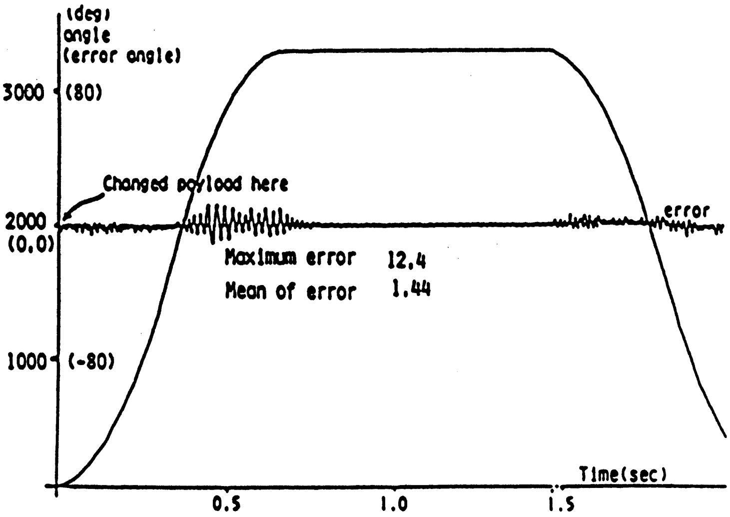

Fig. 14. Time response for changed payload (PI controller)

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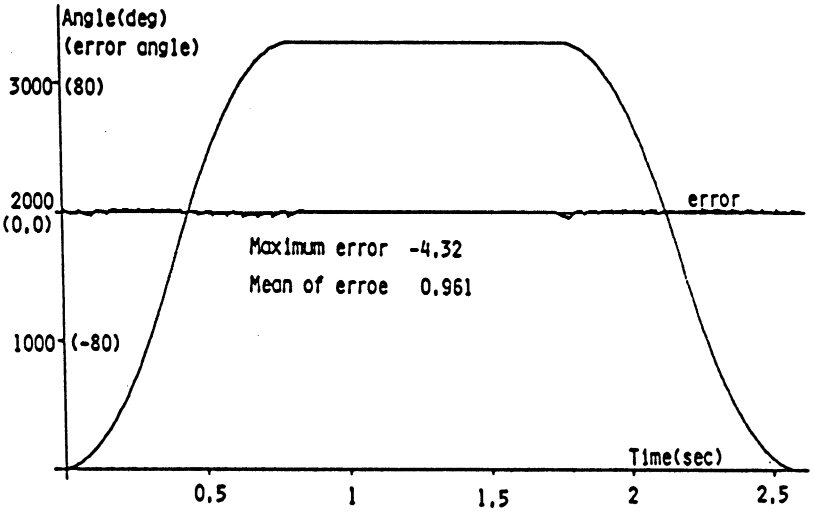

Fig. 15. Time responses of motor angle for DSP controller

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