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DSPs Application in Control Motor-drive Slide Way

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Abstract

The recent rapid and revolutionary in progress in microprocessors and micro-electronics has made it possible to apply modern control theory to implement on digital processors. Because an increasingly availability and low-cost of suitable digital hardware, microprocessors such as the Texas Instrument (TI) TMS320C50 fixed-point digital signal processor (DSP) are increasingly being used to implement algorithms for the control of a robust and fast dynamic feedback system. This paper represents an implementation of the TMS320C50 DSP and particularly the TMS320C50 DSP Starter Kit (DSK) as a digital PID controller. The main objective is to study steps approached to implement and evelop a PID control algorithm embedded on the DSK board in order to control the table position of a positioning-stage with stepping-motor-drive (Slide-way), which subjected to a position command.

1. Introduction

Digital Signal Processors (DSPs) is a special purpose microprocessor designed for supporting a signal processing system. The main task of the DSPs in digital control applications is a signal processing system that executes algebraic algorithms inherent to the control of feedback system, together with analysis and manipulate control signals in the system. In a DSP-based control system, the control algorithm is implemented via software, so there is no components aging or temperature drift associated with this type of control systems. Additionally, sophisticated algorithms, such as PID (Proportional-Integral-Derivative) control algorithm, can be implemented and easily modified to achieve a prefer system performance.

The objective of this paper emphasizes on the DSPs application in digital control area by studying an implementation of a digital PID position controller on a positioning-stage system (motor-drive slide-way) Fig.1. The controller's hardware and software are developed to work on the Texas Instrument (TI) TMS320C50 DSP Starter Kit (DSK) [4, 5] in order to achieve position caccuracy of ±5 μm range.

As illustrated in Fig.2, the positioning-stage movement is implemented by means of stepping motor and ball screws. The stepping motor is controlled by power driven unit with pulse and direction signal. The control signal from D/A port of the TMS320 DSK board is connected to the converting circuit to convert to the pulse and direction command for the stepping drive. The table position is taken by a LVDT (Linear Variable Differential Transformer) gauging transducer with measurement range of ±2.5 mm. The position output is converted to an analog signal by power amplifier and connected to the D/A port of the TMS320 DSK board.

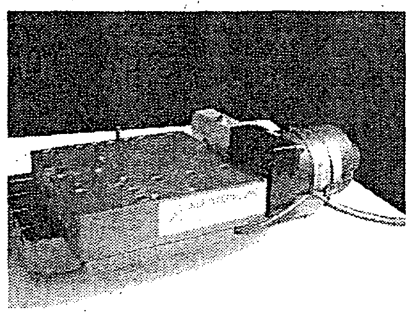

Fig. 1 Positioning-stage with stepping motor drive

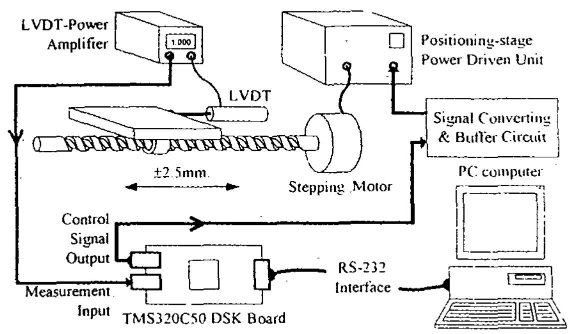

Fig. 2 The position control system connected schematic

This paper based on my MSC. Project at Coventry University (7), which consists of four sections. Section two deals with the PID controller and its tuning technique. Section three the controller's hardware and software implementations are proposed, and the results of experiment are shown in section four.

2. Digital PID Controller and Tuning Technique

2.1 Digital PID Controller

The general form of the PID algorithm [1, 2] can be described as:

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de}{dt} \qquad [1]$$

Where

$u(t)$ = controller output
$e(t)$ = error signal ($e = y_{setpoint} - y$)
K_P = proportional gain
K_I = integral gain
K_D = derivative gain

2.2 Numerical PID parameters

Equation (1) is a continuous-time PID equation used for an analog technique, but for digital control technique, the equation has to convert into a discrete-time equation by using numerical approximation.

For proportional term, the discrete-time ($t = kT$) form is simply implemented by replacing the continuous variable with their sampled versions. Hence,

$$K_P e(t) = K_P e(kT) \quad (2)$$

To approximate integral term, numerical integration base on the trapezoidal approximation [3] is applied. Therefore,

$$K_I \int_0^{kT} e(t)\,dt = \frac{K_I T}{2} \sum_{j=1}^{k} \{e[(j-1)T] + e(jT)\} \quad (3)$$

Similarly with the integral term approximation, the approximated differential term can achieve by using differential approximation. This method is to use the first order backward difference with 2-points approximation. Hence,

$$K_D \frac{de}{dt} = K_D \left(\frac{e(kT) - e[(k-1)T]}{T} \right) \quad (4)$$

Summing equation (2), (3) and (4), therefore the PID algorithm can be represented as follows,

$$u(kT) = K_P e(kT) + \frac{K_I T}{2} \sum_{j=1}^{k} \{e[(j-1)T] + e(jT)\} + K_d \left(\frac{e(kT) - [(k-1)T]}{T} \right) \quad (5)$$

The sampling number of k and the instant time interval T can be substituted by the index of n with the following relation,

$n = kT$;where n and k = 1, 2, 3, ...

Hence, the general discrete form of the PID algorithm becomes,

$$u(n) = K_P e(n) + \frac{K_I T}{2} \sum_{j=1}^{n} [e(j-1) + e(j)] + K_D \left(\frac{e(n) - e(n-1)}{T} \right) \quad (6)$$

This equation can be simplified as follows,

$$u(n) = u(n-1) + a_0 e(n) + a_1 e(n-1) + a_2 e(n-2) \quad (7)$$

Where the coefficient a_0, a_1 and a_2 are defined as following equations,

$$a_0 = Kp + \frac{K_i T}{2} + \frac{K_d}{T} \quad (8a)$$

$$a_1 = -Kp + \frac{K_i T}{2} - 2\frac{K_d}{T} \quad (8b)$$

$$a_2 = \frac{K_d}{T} \quad (8c)$$

2.3 Tuning the PID parameters

To facilitate the determination of the appropriate values of the PID parameters for any cases where a mathematical model for the system under control is not available, Ziegler and Nichols [1] have suggested the simple and practically useful method. This method is based on a registration of the open-loop step response of the system, which is characterized by two parameters *a* and *L*, as shown in Fig. 3.

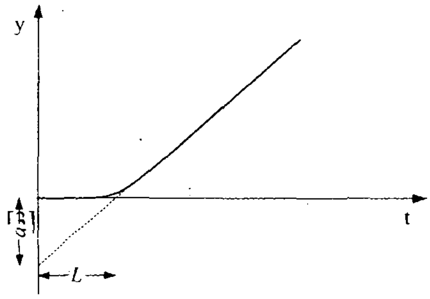

Fig. 3 Characterization of a step response in The Ziegler-Nicholes method

The appropriate PID parameters are determined directly from functions of *a* and *L* according to Table 1.

Controller	K_P	K_I	K_D
PID	$1.2/a$	$2K_P L$	$K_P L/2$

Table 1 PID parameter determining using The Ziegler-Nicholes method

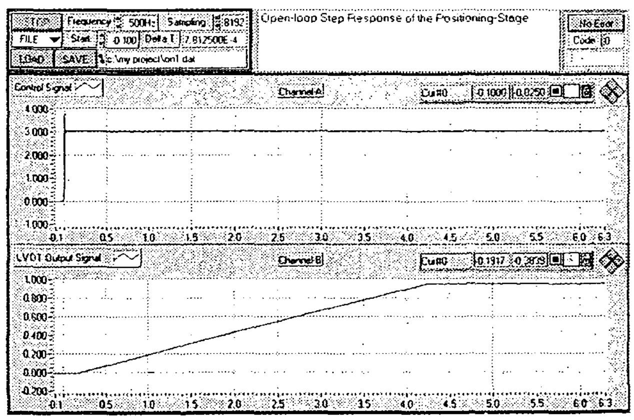

Fig. 4 System step response for open-loop control

Fig. 4 shows a result of the positioning-stage open-loop step response, and the value of a = 0.03 V and L = 0.04 s.

3. Controller Design

3.1 Hardware Implementations

As shown in Fig.2, the stepping motor is controlled by ready-made power unit which required pulse and rotation direction in order to move to the desired position in the desired direction. The position command is sent from a personal computer via RS-232 interface, and the command will be converted into voltage level and direction signal. Fig. 5 illustrated the signal converting circuit schematic that used in the controller. The pulse signal is variable frequency generated by absolute and converting the voltage signal of the D/A of the TMS320 DSK. The rotation direction is selected by using digital data-bus as the signal is to switch between low and high.

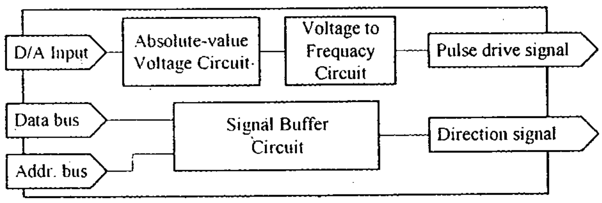

Fig. 5 The signal converting circuit schematic

3.2 Software Implementations

All the control code is executed on the TMS320C50 DSP. The software code is generated and debugged on a personal computer via the TMS320C50 Assembly Development Tools (6). Once the code is assembled, it can be loaded into the TMS320 DSK board to operate the control function. The programming flowchart of the digital PID controller is represented by block diagram as shown in Fig. 6.

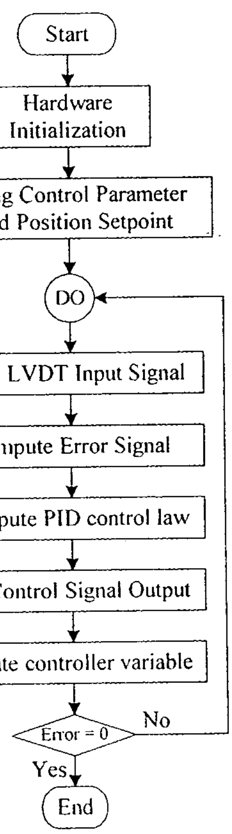

Fig. 6 Flowchart for digital PID controller

The program started by hardware initialization, setting control parameters and reading position set-point. Then, the control loop is started by reading the LVDT signal from D/A port, and computes the error signal. The result will be used in equation (7) for determining the PID control output. Then, the control output will be converted into an analog signal at A/D port, and a digital signal via digital data bus by address 0F32h.

4. Results of Experiments

Experiments have been conducted for testing the complete system to observe the system output response. The spectrum analyzer is used to connect to the output of the D/A port and the input of the A/D port, as shown in Fig. 6, in order to observe the system response. The experiments carried out here are the system with the On/Off control algorithm and the PID control algorithm for comparison with each other. The started position for test system is at –0.2 mm and will approach to the setpoint position at 0.0 mm with motor driven frequency at 500Hz.

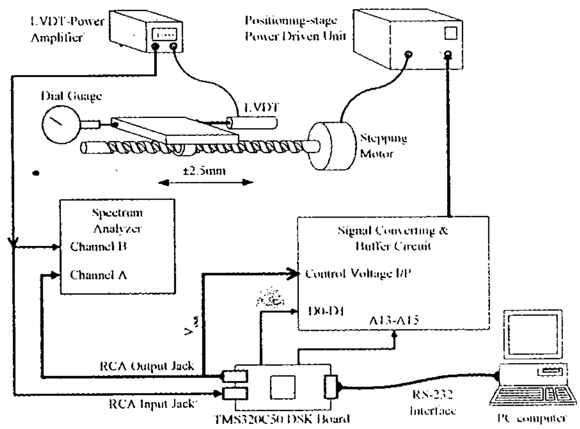

Fig. 7 Parts and circuit connecting in the experiment

Fig. 8 shows the result of system response when the positioning-stage is under control by the On/Off control algorithm. The table approaches to the setpoint with settling time (t_s) of 0.4 second and steady-state error around the setpoint of ±7 μm.

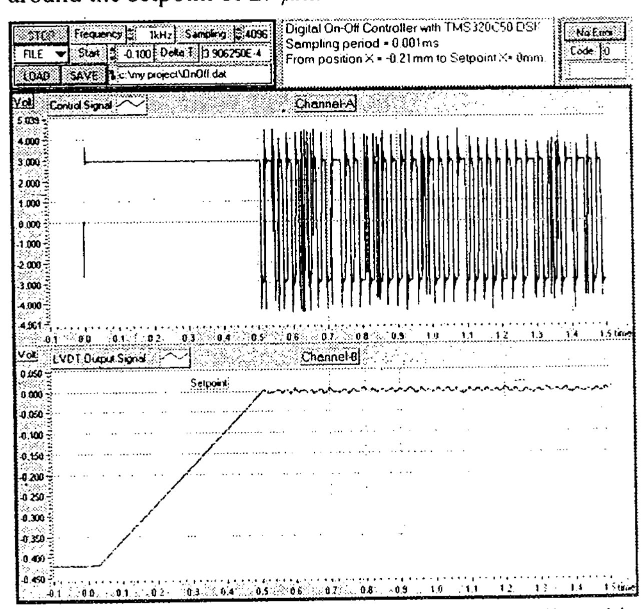

Fig. 8 System response for digital On/Off controller with Steady-state error of ±7 μm and t_s = 0.4 s

Fig. 9 shows the result of system response when the positioning-stage is under control by the PID control algorithm. The PID parameters have been determined by using the Ziegler-Nicholes method, table 1. The value of

K_P is 40, K_I is 3.2 and K_D is 0.8. The table approaches to the setpoint with settling time (t_s) of 0.84 second and steady-state error around the setpoint of ±2.5 μm.

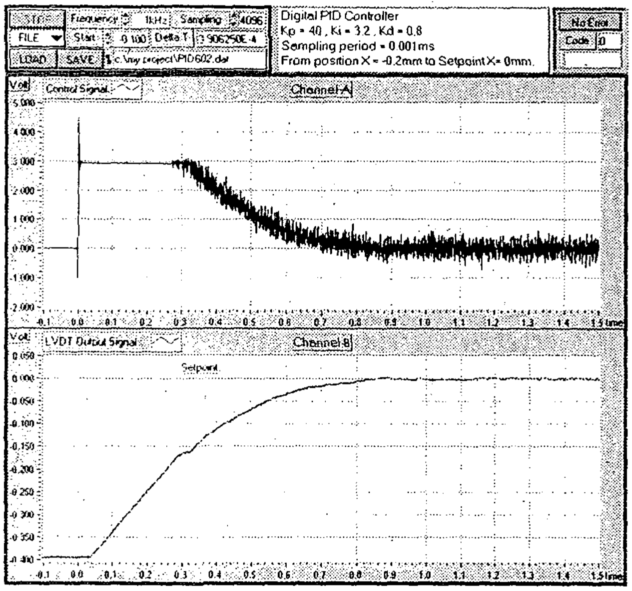

Fig. 9 System response for digital PID controller of $K_p = 40$, $K_i = 3.2$ and $K_d = 0.8$, $t_d = 35$ ms and $t_s = 0.84$ s

6. Conclusion

This paper has presented the steps approach to the DSPs application in control motor-drive slide-way based on the fixed-point arithmetic processor, TMS320C50. The implemented method associated with the digital PID control algorithm. The results of an implementation have shown that the DSP-based controller can achieve the performance and robustness as that of the classical PID controller. The precision of the system is within ±2.5 μm range after settling to the setpoint. Also, the system response can be tuning via modification of the controller gains (K_P , K_I and K_D), which can be done on software development level without modification of any system hardware.

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References

[1] K.Astrom and T.Hagglund, "PID Controller: Theory, Design, and Tunning", 2nd Edition, ISA, USA 1995, pp. 61-98, pp. 135-136.

[2] Richard C.Dorf and Robert H.Bishop, "Modern Control System", 7th Edition, Addison-Wesley Publishing, USA 1995.

[3] Steven C.Chapra and Raymond P.Canale, "Numerical Methods for Engineering", 2nd Edition, McGram-Hill, USA 1985, Pp.139-140.

[4] TMS320C5x DSP Starter Kit User's Guide, literature number SPRU101a, Texax Instruments (TI), USA 1996.

[5] TMS320C5x User's Guide, literature number SPRU056d, Texas Instruments (TI), USA 1995.

[6] TMS320C1x/C2x/C2xx/C5x Assembly Language Tools User's Guide, literature number SPRU018d, Texax Instruments (TI), USA 1995.

[7] Satienpong Huyanan, "DSPs Application in Control Motor-drive Slide-way", Coventry University, UK 1998.