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Microcomputer-Aided Design for A Digital Adaptive Control System

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적응제어 시스템을 위한 마이크로컴퓨터 지원설계

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초 록

본 연구에서 디지탈 적응제어 시스템 설계를 위한 마이크로 컴퓨터 지원설계기법과 프로그램(DACS)을 개발 하였다. 이 프로그램은 Intel 80286 혹은 80386 CPU에 사용되는 GWBASIC 언어로 작성 되었고, 각 요소의 동특성을 모듈화 시키고, 차분방정식으로 표시하는 시뮬레이션 기법을 제시 하였다. 이 프로그램을 사용하면 디지탈제어에서 중요한 샘플링 시간과 A/D, D/A 변환기의 최적 Bit수를 결정할 수 있다. 적응제어 방법은 온라인 RLS(Recursive Least Squares)파라메터 추정방법을 사용하였고, 실험결과와 잘 일치 되었다. 예제로서 공기예열시스템에 적응제어방법을 적용시켜 설계하였다.

1. INTRODUCTION

Digital controls, implemented by micro-computers, are being widely used in many industirial areas, including metallurgial processes, chemical plants, and thermal power plants, etc.

The digital control is superior to the conventional analog control in several aspects. For example, the former can realize an advanced control algorithm easily through its powerful software.

On the other hand, analysis and synthesis of the digital control are difficult, because the digital control system consisting of the digital controller and the analog process to be controlled, is a hydird system, i.e. a discrete-continuous time system.

In the past, most of the signal transformations implied by the controllers were accomplished by analog hardwares. However, the decreased cost and increased speed of modern microcomputers have permitted the economical use of digital processing of signals to control algorithm in real time. In many real-time application, fixed-point arithmetic is used because it results in faster and more economical implementations, which must be represented by a finite number of bits or a finite wordlength. If the representation is not exact, there will be quantization errors which must be properly handled by the system designer if the application is to be suceessful. For a digital control system, the sampling time, the computational delay, the finite wordlength of the

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computer, and the finite wordlength of the interface device (A/D and D/A converter) must be properly coordinated by the designer to balance the system cost and performance characteristics.

The first objective of this paper is to present a practical and realistic scheme for simulating a digital adaptive control system on the microcomputer. The simulation scheme is implemented using the interactive programming language GWBASIC which is suitable for Intel 80286 or 80386 microprocessor. Since the sampling time, the computer wordlength, and the wordlength of the associated interface device are all independent within a digital system, the simulation allows analysis of each componet of the system. Result can be displayed in a tabular (numeric) form, or saved in a disk file to be displayed graphically. This program package is tentatively called DACS (Digital Adaptive Control System). The second objective of the paper presents a microcomputer-aided design method using this DACS program to analyze a digital adaptive control system for an air preheating system. The air preheating system demonstrated on this study is a self-contained process and control equipment. It has the basic characteristcs of a large plant, enabling distance /velocity lag, transfer lag, system response, external control to be demonstrated. In this equipment, air drawn from atmosphere by a centrifugal blower is driven past a heater grid and through a length of tubing to atmosphere again. The process consists of heating the air flowing in the tube to the desired temperature level, and the purpose of the control equipment is to measure the air temperature, compare it with a value set by the reference and generate a control signal which determines the amount of electrical power supplied to a correcting element, in this case a heater mounted adjacent to the blower.

In the process the system dynamics is not constant but varies with the angle of blower shutter, the location of measurement device, and the external disturbance (environment temperature). Although the effects of small changes on the dynmic characteristics are attenuated in a feedback control system, if changes in the system parameters and environment are significant, a satisfactory system must have the ability of adaption.

In an adaptive control system, the dynamic characteristics must be identified at all times so that the controller parameters can be adjusted in order to maintain optimal perfomance. For this example, a recursive least squares(RLS) parameter estimation algorithm and an increased-order deadbeat control algorithm ' were applied to the air preheating system.

Consequently, the results obatained from the digital simulation are compared to those obtained experimentally using actual real-time systems. And also the adquate sampling time, the numberof bits of ADC and DAC can be determined through the sumulation results.

2. DIGITAL PARAMETERADAPTIVE CONTROL SYSTEM.

The structure of a digital paramter adaptive control system is shown in Fig. 1. It consists of the basic control loop and the superimposed adaptation mechanism. The adaptation mechanism again consists of a recursive parameter estimator for the parameter identification which is performed on the basic of only input and output signal measurements, and an adjustement mechanism which calculates the controller gains from the estimates of the system parameters. The adaptive mechanism is performed on the microcomepter. The discrete output (manipulated variable) of the digital computer is transmitted to the system through the digital-to-analog converter(DAC), and the analog output of the preamplifier is fed to the microcomputer via the analog-to-digital converter(ADC).

The microcomputer-aided design for the air preheating system is based on the system shown in Fig. 1. The simulation is written to represent events they would occur in an actual real-time system. Since the sampling time, the computer wordlength used to store the coefficients, and the wordlength of the DAC and ADC effect the performance of the system, these parameters can be varied interactively. For example, the simulation scheme allows the user to vary the number of bits of the ADC and DAC and the sampling time. The computer wordlength is fixed with 16 bits since the simulation program run on the Intel 80286 or 80386.

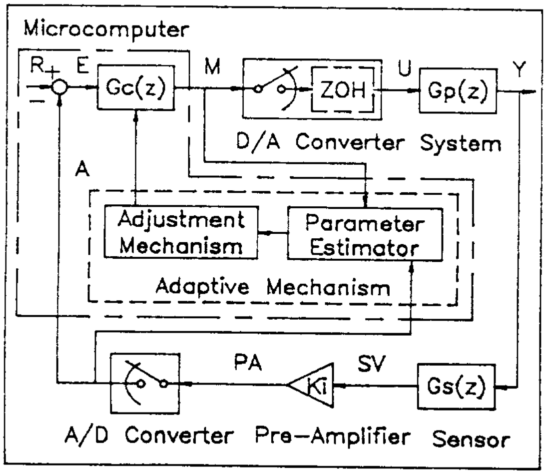

Fig. 1 Digital adaptive control system block diagram

3. ADAPTIVE CONTROL SYSTEM MODELLING

In order to make the effective computer programs, it is desired to modulize each block in such a way that it can be expanded with new parts or replaced by new blocks without too much effort. For simulation purpose, the digital adaptive control system can be depicted in the modulized block diagram shown as Fig. 2.

The system equation of each module is represented by the difference equations as follws :

(1) Control algorithm [M1] :

The control algorithm selected in this example is a deadbeat controller of increased order[1]. The difference equation of the controller can be described as follows :

$$M(k) = M(k-(d+1))*P1+M(k-(d+2))*P2 + e(k)*Q0+e(k-1)*Q1+e(k-2)*Q2 \quad (1)$$

where M(k) and e(k) are the sampled output of the controlled and the sampled error signal at the k-th instant time. P1, P2, Q0, Q1, and Q2 are the constants to be determined by the adjustment mechanism [M2] in the following.

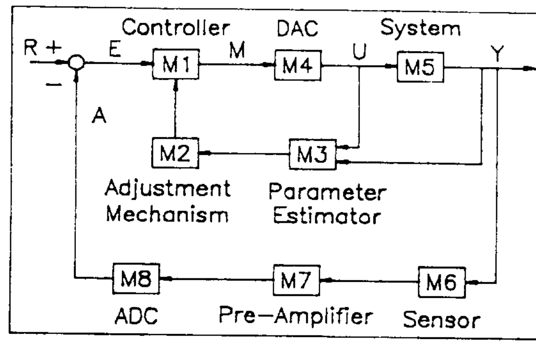

Fig. 2 Module block diagram for simulation

(2) Adjustment mechanism [M2] :

The following equation (Eq. 2.-Eq. 6) are derived from the design of the increased oreder to calculate the constants.

$$Q0 = 1/((1-A1(k))*B1(k)) \quad (2)$$
$$Q1 = Q0*(A1(k)-1)+1/B1(k) \quad (3)$$
$$Q2 = Q0*(-A1(k))+B1(k)/A1(k) \quad (4)$$
$$P1 = Q0*B1(k) \quad (5)$$
$$P2 = Q0*(-B1(k))+1 \quad (6)$$

where Q0, Q1, Q2, P1, and P2 are the constants in the Eq. 1. A1(k) and B1(k) are parameter estimates calculated by the recursive least squares method in the follwing.

(3) Parameter estimator [M3] :

The recursive least squares parameter identification[1] has been used for the contol of the air preheating systm. The RLS algorithm is the following :

$$E(k) = E(k-1)+L(k)*[Y(k)-R(k)*E(k-1)] \quad (7)$$

$$E(k) = [A1(k), B1(k)] \quad (8)$$
$$R(k) = [-Y(k-1), U(k-(d+1))] \quad (9)$$
$$L(k) = P(k)*R(k)/R(k)*P(k)*R(k)+G \quad (10)$$
$$P(k+1) = [I-L(k)*R(k)]*P(k) \quad (11)$$
$$P(0) = W*I \quad (12)$$

where E(k) is the system parameter estimates vector and R(k) are the system input and output data vector, I is the unit matrix, Al(k) and Bl(k) are the system parameter estimates at the k-the instant time. Y(k) is the system output, U(k) the system input, L(k) correcting vector, E(O) is the initial system parameters estimates. E(O) and P(o) must be larger than zero, and must be defined by the designer. G and W are the constants and properly selected by the designer. In this case, G=10000 and W =1 were selected after simulations by the trial-and-error inspections.

(4) Digital-to-analog converter [M4] :

In the example an unipolar type DAC has been used. The difference equation of the DAC is follows :

$$U(k) = OVMAX*M(k)/(2**N-1) \quad (13)$$

where U(k) is the output of the DAC at the k-th instant time, N is the number of bits, and OVMAX is the nominal output voltage of the DAC.

(5) System [M5] :

For the example of an air preheating system, the system dynamics is assumed to be the first order with time delay. This system can be described by the following difference equations.

$$Y(k) = exp(-T/TP)*Y(k-1) +KP*[(1-exp(-T/TP)*U[k-(d+1)] +(exp(-T/TP)-exp(-m*T/TP) *U(k-(d+2))]$$

and

$$m = 1-(TD-d*T)/T \quad (14)$$

where, Y(k) is the system output at the k-th instant time, U(k-(d+1)) is the output of DAC at the k-(d+1)th instant time, TP is the time constant, KP is the system gain, T is the sampling time, TD is the time delay, d is the time delay constant within the sampling interval.

(6) Measurement device [M6] :

The temperature sensor can be described by the first order dynamics :

$$SV(k)=exp(-T/TS)*SV(k-1)+KS*Y(k) \quad (15)$$

where SV(k) and Y(k) are the output of the sensor and the system at the k-th instant time, KS and TS are the gain and the time constant of the sensor, respectively.

(7) Pre-amplifier [M7] :

This device is for the amplification of the sensor output signal. The equation can be described as :

$$PA(k) = KI*SV(k) \quad (16)$$

where PA(k) is the output of the preamplifier and KI is the gain.

(8) Analog-to-digital converter [M8] :

An unipolar type ADC can be represented as follows :

$$AD(k) = (2**N-1)*PA(k)/IVMAX \quad (17)$$

where AD(k) and PA(k) are the outputs of the ADC and pre-amplifier at the k-th instant time, and IVMAX is the nominal input voltage of the ADC.

4. DACS SIMULATION PROGRAM

The interactive program DACS is for microcomputer-aided parameter identification, controller design, and simulation of control system. It has a modular software structure. Therefore, modules that use alternative dynamics can be easily modified by the user without affecting the remainder of the design package. The programming language used is GWBASIC, which is a general purpose high-level language for Intel 80286 and/or 80386 CPU.

This program consists of main program which contains 8 subroutines (or modules) and a graphic program. Each subroutine can be modified and /or replaced by the user. All data generated by the program are stored in data files. The operater's dialogue is CRT-terminal oriented. The input data, the results of each step and the final output can be displayed on the monitor and a hard copy obatained on the line printer.

The output can be plotted on the digital plotter. The flow charts of DACS program and the dialogue-oriented operating system are shown in Fig. 3A and Fig. 3B.

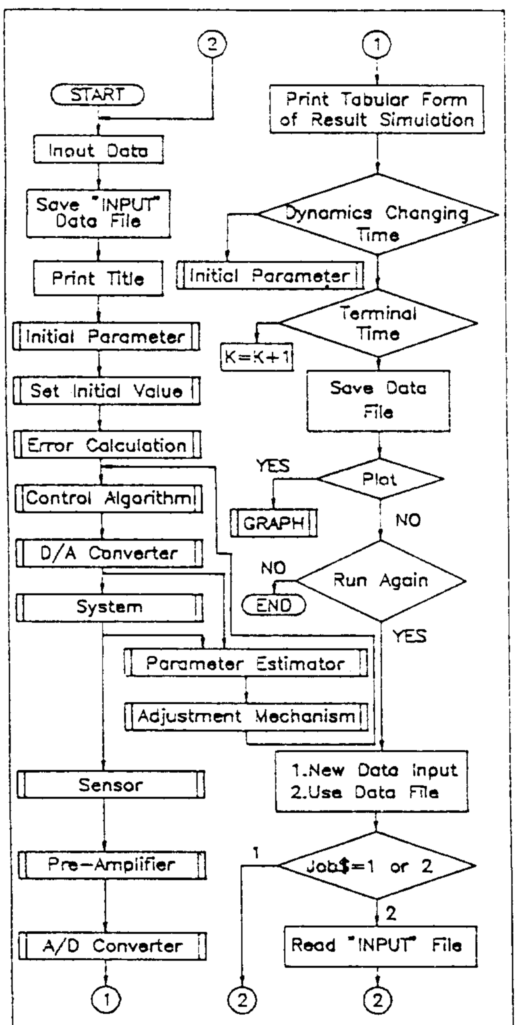

Fig. 3A A flow chart of DACS program

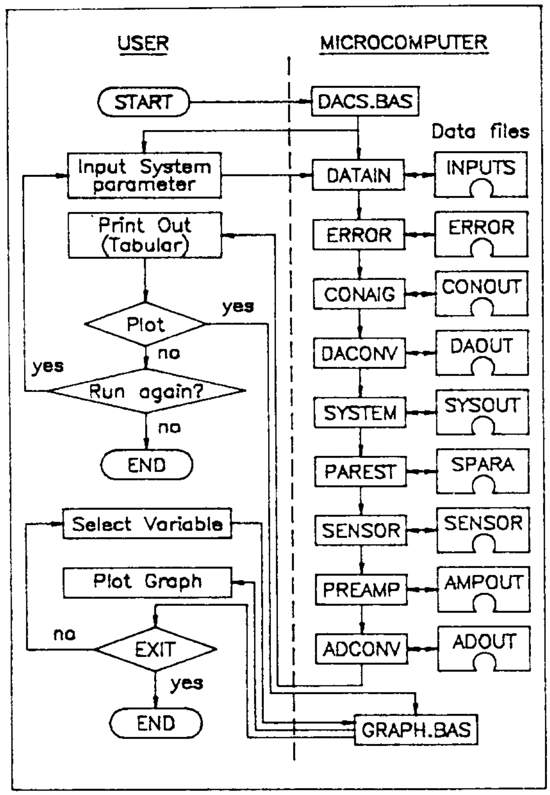

Fig. 3B Operating system flowchart

5. SIMULATION RESULTS AND DISCUSSIONS

The RLS paramter adaptive algorithm and the increased order deadbeat control algorithm were applied to the air pre-heating system whose system models are described in the section 3.

The air temperature is controlled by the input voltage of the heater. The input variables for simulation are listed in Table 1, and the outputs are listed in Tabel 2.

Since the sampling time and the wordlength of the DAC and ADC affect the performance of the system, these parameters can be varied interactively. For example, the simulation scheme allows the user to vary the number of bits of the DAC and ADC as well as the sampling time. The computer wordlength also

Table 1. Input variables of the simulation program

Variables	Computer variabes
Sensor postion	SP
Blower shutter angle	BS$
Change of the blower shutter angle	CBS$
Surrounding temperature	ST
Control algorithm	CON$
Initial greate number	ALPHA
Forgetting factor	RAMDA
Gain of sensor	KS
Time constant of sensor	TS
A/D converter bits	ADBIT
A/D coverter minimum reference input	IMINV
A/D converter maximum reference input	IMAXV
D/A converter bit	DABIT
D/A converter minimum reference output	CMINV
D/A converter maximum reference output	CMAXV
Pre-amplifier gain	KI
Min. value of controlled value	MINCON
Max. value of controlled value	MAXCON
Initial value	INIV
Required value	REQV
Sampling time	SAMPT
Time interval for print output	OUTSAMP
Terminal time	OPERT
System dynamics change time	CTIME

Table 2. Ouput variables of the simulation program

Variables	Computer variabes
Analog value of error	E
Digital value of manipulated variable	M
Analog value of controlled variable	Y
Analog value of D/A converter	U
Analog value of sensor output	SV
Digital value of D/A converter	A

affects the performance of the system[2].

In this case the variation of computer wordlength has not been considered, and the computer wordlength is fixed with 16 bits for the microcomputer. The algorithm is implemented using a floating-point arithmetic on the Intel 80286 CPU.

Several experimental[4] were conducted in order to verify the simulation scheme. Fig. 4 depicts that the result of simulation and experiment are well agreed under the conditions of 12 bits ADC and DAC, 0.3sec sampling time, blower shutter angle 60, sensor position 1, and the increased order deadbeat control action.

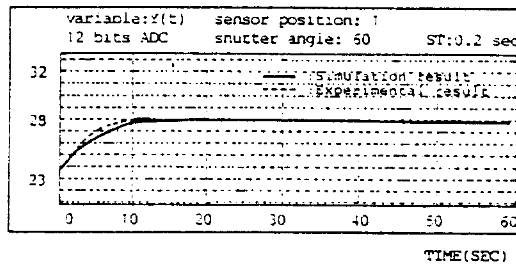

Fig. 4 Comparision of simulation result with experiments

Fig. 5(a) and 5(b) show the effect of sampling time to the perfomace of the control system. Fig. 5(a) is the simulation result of the temperature when the sampling time=0.2sec is applied, whereas Fig. 5(b) is for T=1sec. It shows that the response of Fig. 5(a) is settled down faster than that of Fig. 5(b) under the same conditions.

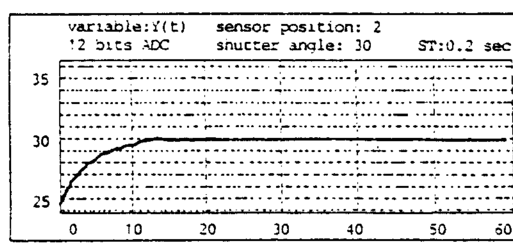

Fig. 5(a) Sampling Time=0.2sec

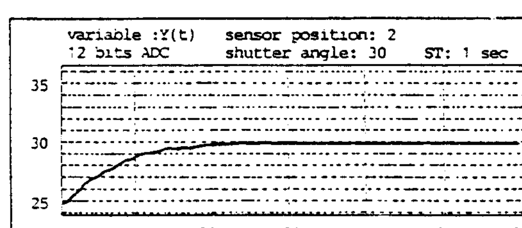

Fig. 5(b) Sampling Time=1sec

Fig. 5 Time responses(Y) with different sampling times

Fig. 6 shows the results of varying the ADC and DAC wordlength from 4 to 16 bits. Fig. 6 (a) is the temperture response when 4 bits-ADC and DAC are used. Fig. 6(b), Fig. 6(c), and Fig. 6(d) are for 8 bits, 12 bits, and 16 bits, respectively. As a result, if the wordlength of the interfaces (ADC and DAC) relatively small, quantization error is introduced so that the steady-state error exists and the shape of the response curve itself is distorted as shown in Fig. 6(a). The results of Fig. 6(c) and Fig. 6(d) are the same, which means that over 12 bits interfaces have good resolution. Since the cost of the interface is usually expensive and depending on the number of bits, this simulation scheme becomes a practical tool for determining acceptable system performance by using an appropriate wordlength of the interface, thus the cost of control system can be reduced. Fgi. 7 represents overall system time responses including the system parameter estimates for the air preheating system. In this figure, the dynamic behavior of each module can be visualized and investigated.

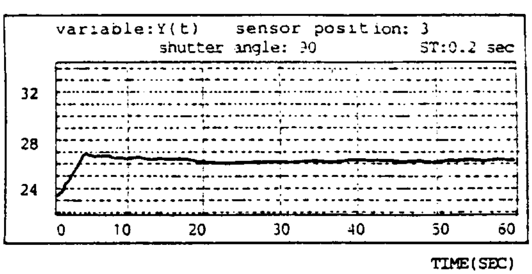

Fig. 6(a) 4 bits-ADC and DAC

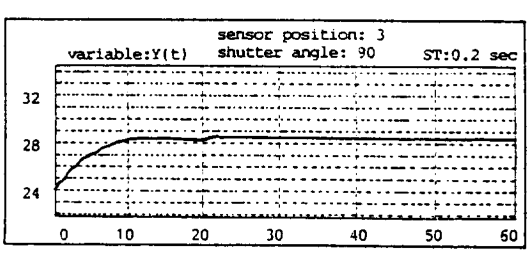

Fig. 6(b) 8 bits-ADC and DAC

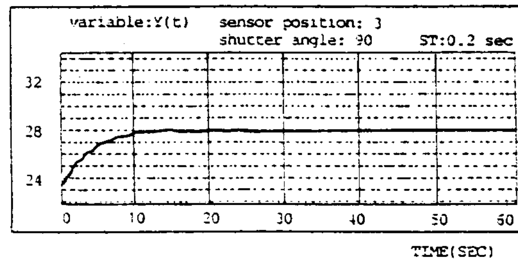

Fig. 6(c) 12 bits-ADC and DAC

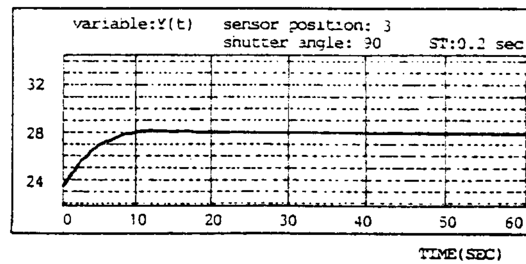

Fig. 6(d) 16 bits-ADC and DAC

Fig. 6 Time responses(Y) with respect to the number of bits of ADC and DAC

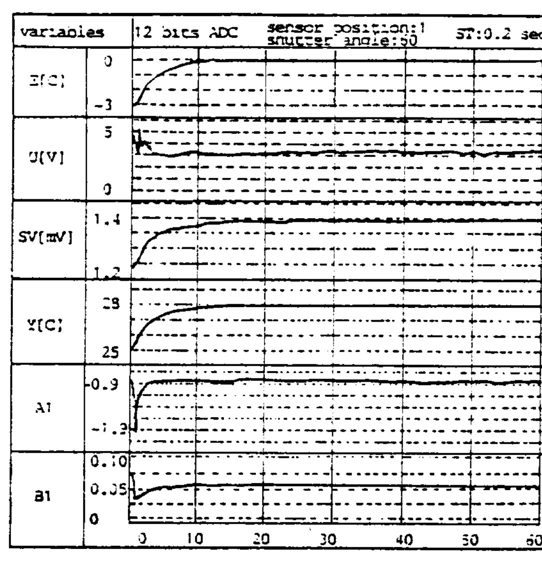

Fig. 7 Overall system responses for the air-preheating control

6. CONCLUSIONS

A simulation method has been presented to analyze and design for a digital adaptive control system via the microcomputer-aided design program (DACS). As an example, and air preheating system was employed. The system designer can select the sampling time, the wordlength of the ADC and DAC, as well as the control algorithm through the simulation results using the program DACS for the better system performace and the cost. The simulation results and the actual experimental results compared favorably.

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