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Microprocessor-Based Digital Controller Design with Changing the Damping Ratio

(감쇄비 변화를 마이크로프로세서로 이용한 계수형 제어기의 설계)

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要 約

마이크로프로세서는 공학분야에서 점차 보편화 되고 있다. 본 논문에서는 제어계의 감쇠상수 ζ을 변화하는 제어기를 마이크로프로세서로 구현해 본 것이다. 결과는 응답시간면에서 긍정적으로 개선되었음을 볼 수 있었다.

Abstract

As a general-purpose device, the microprocessor has made a large impact on many area of engineering. In this paper, a controller has been implemented using microprocessors allowing the damping ratio ζ to be changed dynamically in control systems. The results show definite improvement in response time.

I. Introduction

Over the past several years, the use of digital electronics, in particular microprocessors, for control implementation has been increased significantly.

The advent of the microprocessor continues the trend toward lower-cost computers in the process control industry. Just as the minicomputer made it possible for simpler systems to have greater flexibility, analog, hard-wired digital, and computer control system may be replaced by the microprocessor-based systems, increasing capability and lowering cost. In small systems, the primary control element may be a microcomputer. In large systems, the microcomputers may be used to implement subsystems controlled by a large master computer. The microcomputer is also ideal for self-contained control in remote location.[2]

The use of microprocessors for control implementation results, in many instances, in reduced control cost, smaller, and more sophisticated controllers, and controller with lower power requirements and integrated circuit reliability. Also, the use of microprocessors for implementing control logic allows the use of modern control theory leading such as system identification, modeling, filtering, and multivariable control methodology.

II. Digital Control Systems

The digital controller in the continuous system studied in this paper contains an 8 bit

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CPU(Intel 8080), 256 bytes RAM, 4K bytes ROM including monitor ROM, and two programmable peripheral interface chips(Intel 8255). Analog-to-digital(A/D, ADC 0800p) and digital-to analog(D/A, AD 558) converters are interfaced to the microcomputer with a seven-to-one *multiplexer* A/D *converter*. The plant is simulated by a TR-48(Electronic Associate, Fig. 1) analog computer and interfaced to the Intel 8080 microcomputer through the A/D and D/A converters.

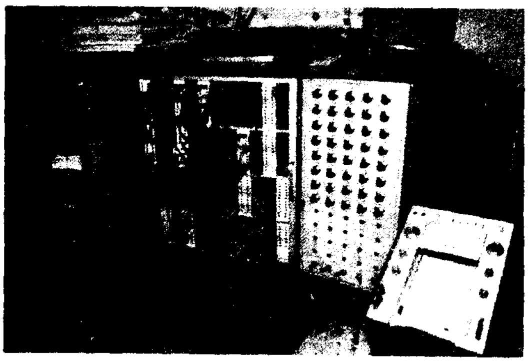


Fig. 1. Analog computer (TR-48, Electronic Associates Inc.)

Another digital controller designed is based on a 16 bit TI 9900 microprocessor, with A/D and D/A converters. The TI 9900 CPU is more powerful than the Intel 8080.

The block diagram of the control configuration is shown in Fig. 2 and the block diagram of the 8080-based digital controller is shown in Fig. 3.

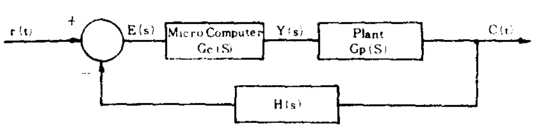


Fig. 2. Control configuration.

The 8 bit A/D converter in the Intel 8080 system has the voltage range from −8.0 to +9.0 volts and the input voltage will be converted to 8 bit numbers OO to FF in hexdecimal number. The D/A converter converts OO_{16} to FF_{16} to −10 volts to +10 volts.

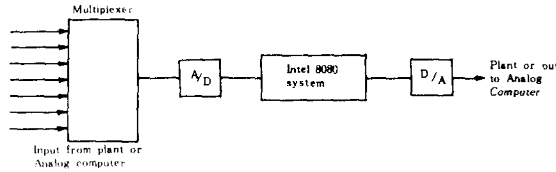


Fig. 3. 8080 microprocessor system used as digital controller.

One of seven analog input channels is selected by a 3 bit address to the AD 7503 channel select terminal(A0-A2). The 3 bits were set or reset by the CPU through 8255 (PPI). The microcomputer system has an external clock which controls the sampling rate of A/D conversion. The range of the sampling rate is from 0.019 Hertz to 156 Hertz.

The start of conversion signal in the A/D can be initiated by the external clock or by the CPU.

Another microcomputer used in the digital controller implementation is the 16 bit TI 9900 microprocessor. This system has 12 bit A/D and D/A converters which have voltages from −10.0 to +10.0 volts. The D/A converters act as write only memory. The converters use 12 bit 2's complement number representation.

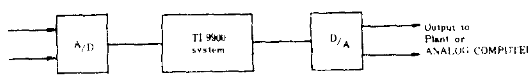


Fig. 4. Another digital controller using TI 9900 systems.

III. Digital Controller Algorithm

The overall system including the digital controller is shown in Fig. 2. The use of microprocessor in digital controller implementation makes the system very flexible. The system can be used implementing classical proportional-integral-derivative(PID) control as well as quasi-optimal control algorithms.

The transfer function for the system with PID controller in Fig. 2 can be written as

$$\frac{C(s)}{R(s)} = \frac{G_c(s)\,G_p(s)}{1 + G_c(s)\,G_p(s)\,H(s)} \qquad (1)$$

or

$$\frac{E(s)}{R(s)} = \frac{1}{1 + G_c(s)\,G_p(s)\,H(s)} \qquad (2)$$

where $C(s)$ = the output
$R(s)$ = the reference input
$E(s)$ = the actuating signal
$G_p(s)$ = plant
$G_c(s)$ = the compensator which may be PID controller and lead and/or lag network.

When the compensator $G_c(s)$ in Fig. 2 is implemented by the microprocessor-based digital controller, the controller has to compute a difference equation simulating the compensator $G_c(s)$. As an example, consider a lead-lag network, of which the transfer function is given as

$$\frac{Y(s)}{E(s)} = G_c(s) = \frac{A\,(1+T_1 S)\,(1+T_2 S)}{(1+\alpha T_1 S)\,(1+T_2 S/\alpha)}$$

$$\alpha > 1$$

$$T_1 > T_2 \qquad (3)$$

or

$$\alpha T_1 T_2 \ddot{y}(t) + (\alpha^2 T_1 + T_2)\,\dot{y}(t) + \alpha y(t) =$$
$$= A\alpha[T_1 T_2\,\ddot{e}(t) + (T_1+T_2)\,\dot{e}(t) + e(t)] \qquad (4)$$

The difference equation simulating the continuous system given in equation (4) is

$$y(nT) = -\frac{\alpha C_2}{C_4}\,y[(n-1)T] - \frac{C_5}{C_4}\,y[(n-2)T]$$
$$+ \frac{A\alpha}{C_4}\,[C_1 e(nT) + C_2 e(n-1)T]$$
$$+ C_3 e[(n-2)T] \qquad (5)$$

where $C_1 = 12T_1T_2 + 6T_1 + 6T_2 + T^2$
$C_2 = 10T^2 - 24T_1T_2$
$C_3 = 12T_1T_2 - 6T_1 - 6T_2 + T^2$
$C_4 = 12\alpha T_1 T_2 + 6\alpha T_1 + 6T_2 + \alpha T_2$
$C_5 = 12\alpha T_1 T_2 - 6\alpha T_1 - 6T_2 + \alpha T_2$

The microprocessor-based digital controller must solve equation (5) during sampling period to determine the plant input $y(nT)$.

IV. Quasi-Optimal Control

A computer-based digital controller can be used to implement optimal control system based on modern control theory. Since the computational capability of a microprocessor is limited, microprocessor-based-controller can be used to implement only simple control algorithms which are quasi-optimal. We used quasi-optimal in this paper means that there is no overshoot and fast rise and settling time to change a damping ratio in the control systems.

In this paper a simple control algorithm, which is an implement over the classical compensator in the response time, is implemented by the control system in Fig. 2. The control problem considered here is a regulator problem in which the output $c(t)$ should reaches a constant reference input $r(t)$ as soon as possible.

This problem is a minimum terminal time control problem with constant $c(t)=r(t)$. This repeating time for looping and calculations are very fast because these 1-ms calculation time caused no problem in these single plant controller. This problem can be solved by optimal control techniques[3] and the functional equation for the optimality of this problem need to be solved for implementation. Usually the computational requirement is beyond the capability of a microprocessor.

The closed-loop system is stable if all roots of the denominator of lie on the Left Half Plane of s-domain and if not, make a pole-zero cancelation using a lead-lag network compensation devices.

Quasi-optimal control algorithms for this problem can be obtained by using the classical feedback control techniques. In this approach when the error $e(t) = r(t) - c(t)$ is large at the beginning, the equivalent damping ratio ζ is changed to large value, e.g. unity(critical)

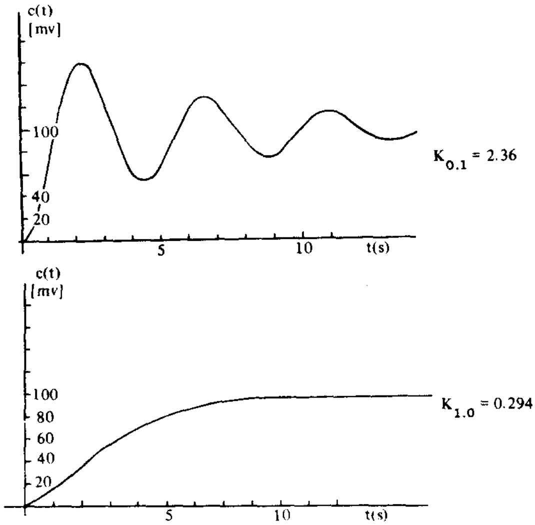


Fig. 5. Output response of analog computer (no compensation).

damping ratio. This prevents c(t) to be oscillatory and approaches r(t) with small error e(t). The switching of the damping ratio of the system is performed by the microprocessor.

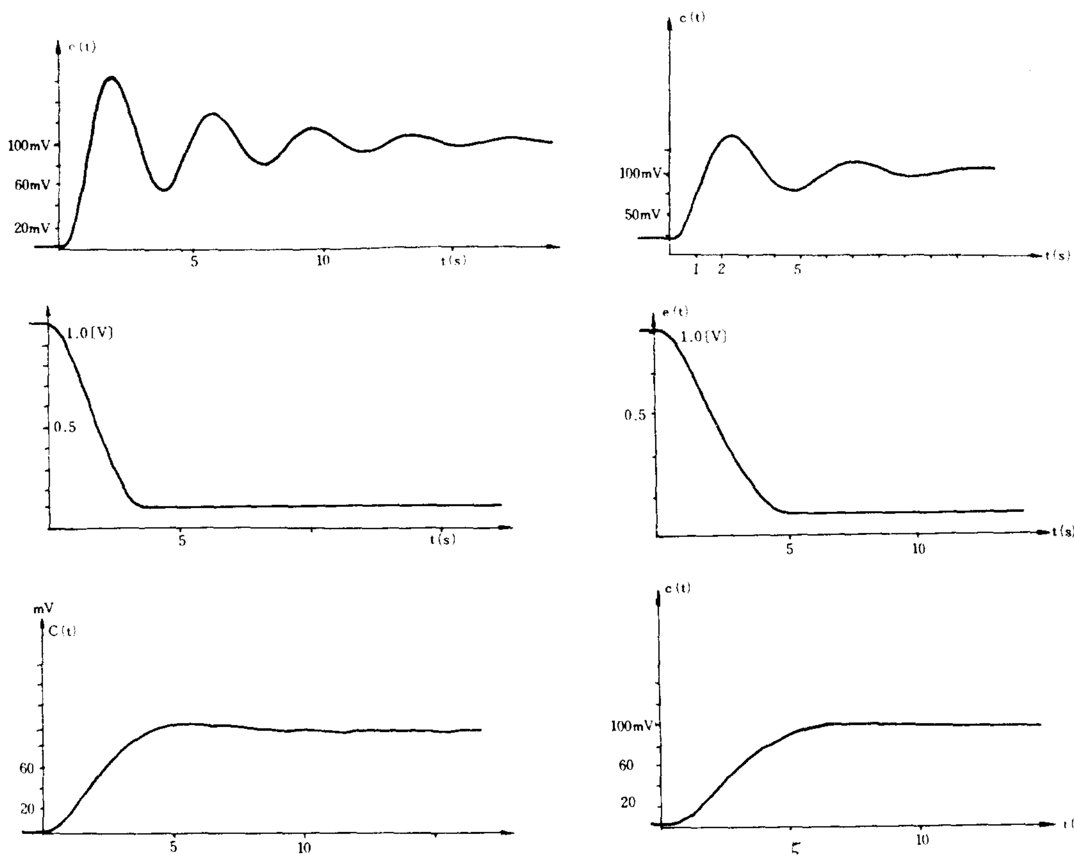
This approach is illustrated by the following example. The system in Fig. 2 has a transfer function incorporating the followings:

$$G_p(s) = \frac{1}{s(s+1)(0.25s+1)}$$

$$G_c(s) = K$$

$$H(s) = 1$$

For this system the equivalent damping ratio ζ can be set by a choosing proper proportional constant K of the compensator $G_c(s)$.



(a) TI 9900 system (b) Intel 8080 system

Fig 6. Output with the digital controller.

The first and second damping ratios are chosen to be 0.1 and 1.0 and corresponding value of K are found to be 2.217 and 0.3001 by using the root locus method. The switching threshold for K is set to be 5% of r(t), i.e., $|e(t)| = 0.05\ r(t)$. The plant $G_p(s)$ is simulated by the analog computer TR-48. The step input response obtained by analog computer for $K_{0.1} = 2.36$ and $K_{1.0} = 0.294$ are shown in Fig. 5. The system response when the microprocessor-based-digital controller case is shown in Fig. 6. Comparing these figures, we can see that there is definite improvement in the response time.

Fig. 7. 8080 microprocessor with A/D and D/A.

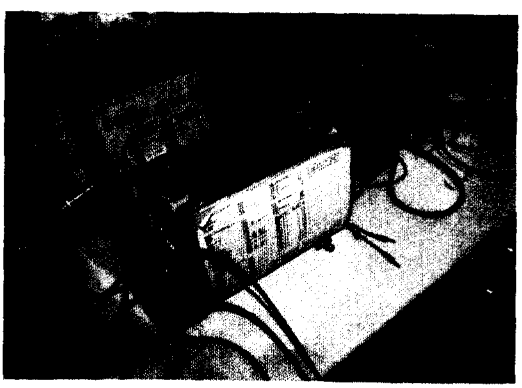


Fig. 8. TI 9900 system.

Conclusion

A procedure is discussed for designing a digital controller using a microprocessor. The

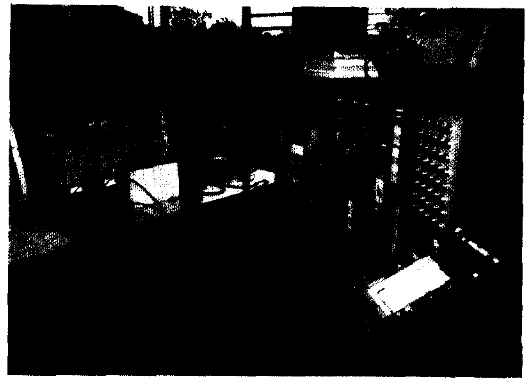


Fig. 9. Experimental view of microprocessor-based digital controller and analog computer.

difference equation has been implemented by software when the sampling frequencies are set very high (about 742 Hz) compared to system frequency, so that there is almost no problem about the updating. The Intel 8080 and TI 9900 microprocessor were chosen because of simple interfacing and good engineering support both in hardware and software development aids.

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