Microcontroller based self-tuning digital PID controller

PETR DOSTÁLEK, LIBOR PEKAŘ, VLADIMÍR VAŠEK, JAN DOLINAY
Department of Automation and Control Engineering
Tomas Bata University in Zlín, Faculty of Applied Informatics
Nad Stráněmi 4511, 760 05 Zlín
CZECH REPUBLIC
{dostalek; pekar; vasek; dolinay}@fai.utb.cz   http://www.fai.utb.cz

Abstract: - Paper deals with implementation of self-tuning digital PID controller on general-purpose 8-bit Freescale 68HC908GB60 microcontroller which is a part of development board M68EVB908GB60 by Axiom Manufacturing. The process is identified using modified recursive least squares method with adaptive directional forgetting resulting in δ-model representation of controlled plant. This representation was chosen in order to achieve lower sampling time periods and mainly better numerical stability of identification process. Control part of algorithm utilizes digital PID controller whose parameters are designed by pole placement method. Developed program equipment works under real-time operating system RTMON for HCS08 which was created on our department. Functionality of the controller was verified by controlling two different educational heat plants models which are used in laboratory lessons of Theory of Automatic Control subject.

Key-Words: - Microcontroller, Freescale 68HC908GB60, self-tuning control, delta models, pole placement

1 Introduction

Present-day very rapid progress in electronics and computer science influences all areas of human activities. Production technology improvements of new microcontrollers lead to their miniaturization, increased central processor unit performance, decreased power consumption and price. Thus modern 8-bit one-chip microcontrollers have enough computing power not only for simple control loops consisting of fixed parameters controllers like PS or PSD. They are able to handle tasks from the origin of modern control methods such as adaptive control. Due to some limitations, mainly in main memory capacity, microcontrollers cannot substitute powerful industrial PCs or special programmable logic controllers, which can work with number of control loops simultaneously. However, area of microcontroller usage is a bit different – in embedded systems that is in systems where is laid stress on low price, compact dimensions, low power consumption, high reliability and immunity against environmental influences and other specific requirements.

This work presents implementation of self-tuning digital PID controller on a member of wide family of 8-bit Freescale HCS08 microcontrollers. Concretely was chosen general-purpose 8-bit Freescale 68HC908GB60 microcontroller which is a part of development board M68EVB908GB60 by Axiom Manufacturing. First part of the paper describes implemented algorithms for process identification and PSD controller design using pole placement method. Next two chapters deal with hardware overview of selected microcontroller including evaluation board basic properties followed by software implementation. Last part of the paper is focused on experimental verification of designed controller.

2 Implemented algorithms

2.1 Process identification

For process identification was used recursive least square algorithm with adaptive directional forgetting. In order to achieve lower sampling time periods and mainly better numerical stability of identification process forward δ-model was chosen (1).

$$\delta = \frac{z-1}{T_0} \tag{1}$$

Identified system is described by second order transfer function in δ-representation (2).

$$G_s(\delta) = \frac{\beta_1\delta + \beta_2}{\delta^2 + \alpha_1\delta + \alpha_2} \tag{2}$$

ARX regression model expressed in compact vector form is described by equation [1]:

$$y(k) = \Theta^T(k)\phi(k-1) + n_s(k) \tag{3}$$

where $\Theta^T(k)$ is vector of parameters of identified system and $\phi(k-1)$ is regression vector.

$$\Theta^T(k) = [a_1, a_2, ..., a_{na}, b_1, b_2, ..., b_{nb}] \tag{4}$$

$$\phi^T(k-1) = [-y(k-1), -y(k-2), ..., -y(k-na), u(k-1), u(k-2), ..., u(k-nb)] \tag{5}$$

Vector of parameter estimations is updated using formula:

$$\hat{\Theta}(k) = \hat{\Theta}(k-1) + \frac{C(k-1)\phi(k-1)}{1+\xi(k)}\hat{e}(k-1) \tag{6}$$

where e(k) is prediction error and C(k) is covariant matrix [1]:

$$\hat{e}(k) = y(k) - \hat{\Theta}^T(k)\phi(k-1) \tag{7}$$

$$C(k) = C(k-1) - \frac{C(k-1)\phi(k-1)\phi^T(k-1)C(k-1)}{\varepsilon^{-1}(k) + \xi(k)} \tag{8}$$

where ε(k) and ξ(k) are defined as:

$$\varepsilon(k) = \varphi(k) - \frac{1-\varphi(k)}{\xi(k)}, \tag{9}$$

$$\xi(k) = \phi^T(k-1)C(k-1)\phi(k-1). \tag{10}$$

The directional forgetting factor φ(k) is calculated using equation (11):

$$\varphi(k)^{-1} = 1 + (1+\rho)[\ln(1+\xi(k-1))] + \left[\frac{(\nu(k-1)+1)\eta(k-1)}{1+\xi(k-1)+\eta(k-1)} - 1\right]\frac{\xi(k-1)}{1+\xi(k-1)} \tag{11}$$

where η(k), ν(k) and λ(k) are defined as:

$$\eta(k) = \frac{\hat{e}^2(k)}{\lambda(k)}, \tag{12}$$

$$\nu(k) = \varphi(k)[(\nu(k-1)+1], \tag{13}$$

$$\lambda(k) = \varphi(k)\left[\lambda(k-1) + \frac{\hat{e}^2(k-1)}{1+\xi(k-1)}\right]. \tag{14}$$

For parameters identification of transfer function (2), vector of parameters and vector of data must be modified to the form of (15) and (16) [2].

$$\Theta^T(k) = [\alpha_1, \alpha_2, \beta_1, \beta_2] \tag{15}$$

$$\phi^T(k-1) = [-\frac{y(k-1)-y(k-2)}{T_0}, -y(k-2), \frac{u(k-1)-u(k-2)}{T_0}, u(k-2)] \tag{16}$$

2.2 PSD controller design using pole placement method

The controller based on the placement of poles of a feedback system is designed so that it stabilizes the closed feedback loop whereas the characteristic polynomial has pre-defined poles. For feedback system the synthesis consists in solving the Diophantine equation:

$$AP + BQ = D, \tag{17}$$

where A, B are polynomials of the plant, Q, P are polynomials of the controller and D is characteristic polynomial, which is defined in the following form:

$$D(\delta) = \delta^4 + d_1\delta^3 + d_2\delta^2 + d_3\delta + d_4 \tag{18}$$

The transfer function of PID controller in δ-modification is [2]:

$$G_R(\delta) = \frac{Q(\delta)}{P(\delta)} = \frac{q_0\delta^2 + q_1\delta + q_2}{\delta(\delta+\gamma)} = \frac{U(\delta)}{E(\delta)}. \tag{19}$$

Solving of Diophantine equation (17) leads to a system of four algebraic equations, which can be written in matrix form:

$$\begin{bmatrix} \beta_1 & 0 & 0 & 1 \\ \beta_2 & \beta_1 & 0 & \alpha_1 \\ 0 & \beta_2 & \beta_1 & \alpha_2 \\ 0 & 0 & \beta_2 & 0 \end{bmatrix} \cdot \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ \gamma \end{bmatrix} = \begin{bmatrix} d_1 - \alpha_1 \\ d_2 - \alpha_2 \\ d_3 \\ d_4 \end{bmatrix}. \tag{20}$$

3 Hardware overview

Self tuning digital PID controller was implemented on development board M68EVB908GB60 by Axiom manufacturing which is based on general purpose 8-bit Freescale microcontroller MC9S08GB60. Board is equipped with number of useful peripherals enabling comfortable development of new applications for this microcontroller. User application can utilize 4 LED indicators, 4 push buttons, 4 position DIP switch, 2x16 character LCD Module, buzzer and potentiometer. For communication purposes it provides two serial asynchronous communication interfaces RS232 with standard DB9-S connectors. Second RS232 interface can be switched to RS422/485 mode in which all signals are redirected to dedicated 5 pin terminal. In case of need other external peripherals can be connected to MCU port (provides all digital I/O) and ANALOG port (provides analog inputs) incorporating all necessary signals including power supply pins. Kit is provided with Freescale binary monitor located in protected area of the internal FLASH memory. Monitor program enables loading and debugging of user program via standard RS232 interface, so there is no need to have specialized BDM adapter. Development board photograph is in Fig.1 [6].

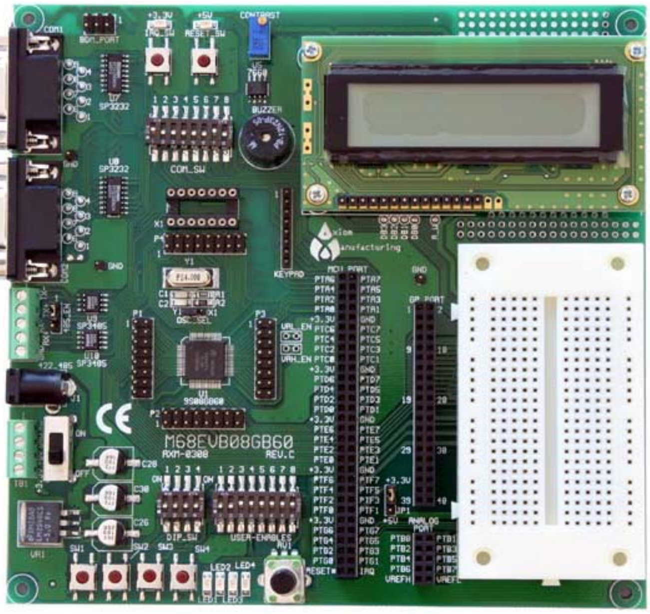

Fig.1. Development board M68EVB908GB60.

3.1 Microcontroller MC9S08GB60

The MC9S08GB60 is low-cost, general purpose, high-performance 8-bit flash-based microcontroller with von-Neumann architecture. Central processor unit with enhanced HCS08 core is fully upward compatible with Freescale 68HC05 family. Their architecture is fully optimized for C language compilers.
On the chip are integrated following modules:

- One 3-channel and one 5-channel 16-bit timer/pulse width modulator modules
- Two serial communication interfaces
- Serial peripheral interface
- Inter-integrated circuit bus module
- Internal clock generator module
- 10-bit analog-to-digital converter with 8-channel analog multiplexer
- On chip 64KB FLASH memory with in-circuit programming capability
- 4KB on-chip RAM
- 56 general-purpose I/O pins (16 high-current pins)
- Software selectable pullups on ports when used as input
- 8-pin keyboard interrupt module
- Watchdog system
- Low-voltage detection
- Illegal opcode and address detection
- On-chip debug module (DBG) [4]

Central processing unit (CPU) features:

- 40 MHz operation at 3V
- 8-bit accumulator (A)
- 16-bit stack pointer (SP) with new stack manipulation instructions
- 16-bit index register (H:X) with index register instructions
- Memory to memory moves without using the accumulator
- Fast 8-bit by 8-bit multiply and 16-bit by 8-bit divide instructions
- 64 Kbytes program/data memory space [5]

4 Controller verification and results

Functionality of the implemented controller was verified by controlling two different real laboratory heat plants using Axiom M68EVB908GB60 development board. Connection with real system was realized via MCU and ANALOG port connectors. Control signal is generated using standard digital output pin with utilization of pulse-width modulation. PWM period was chosen with respect to controlled system dynamics $T_{PWM} = 0.5s$.

Step responses of the heating plant models 1 and 2 are depicted in the Fig. 2 and Fig. 3. They were measured with control signal change from 40% to 60% of its maximum value. Controlled systems were approximated with second order transfer functions (21) for plant 1 and (22) for plant 2. Figures 4 and 5 shows control processes for both heating plants models with utilization of self-tuning PSD controller. Sampling period of the controller was set to 0.5s.

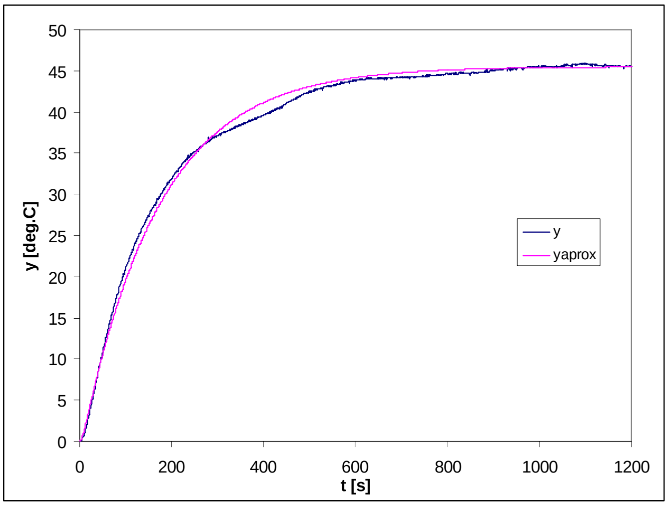

Fig.2. Heating plant model 1 step response.

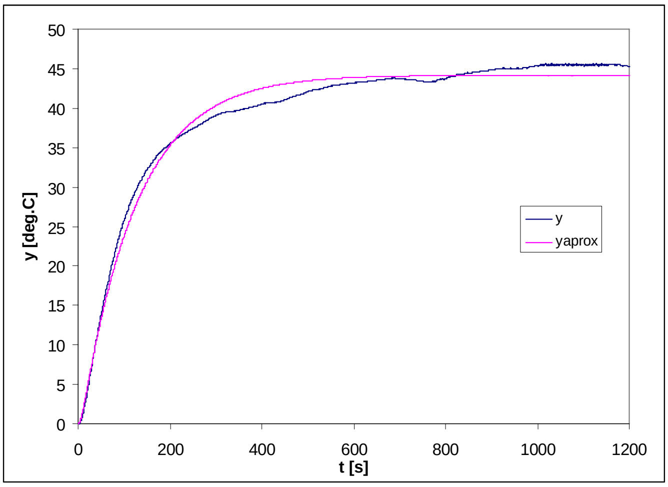

Fig.3. Heating plant model 2 step response.

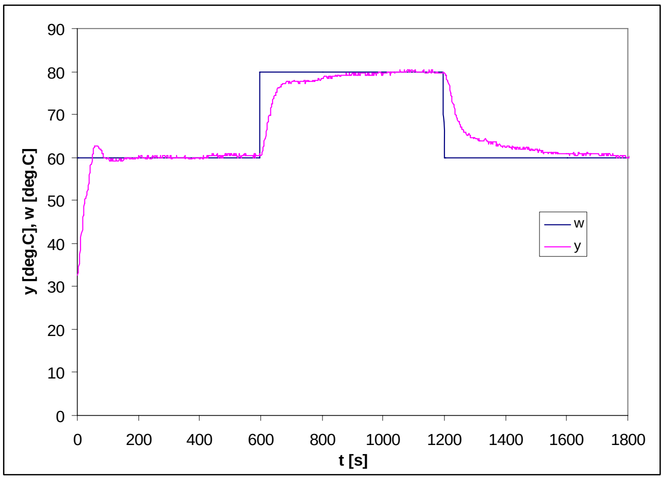

Fig.4. Heating plant model 1 control process.

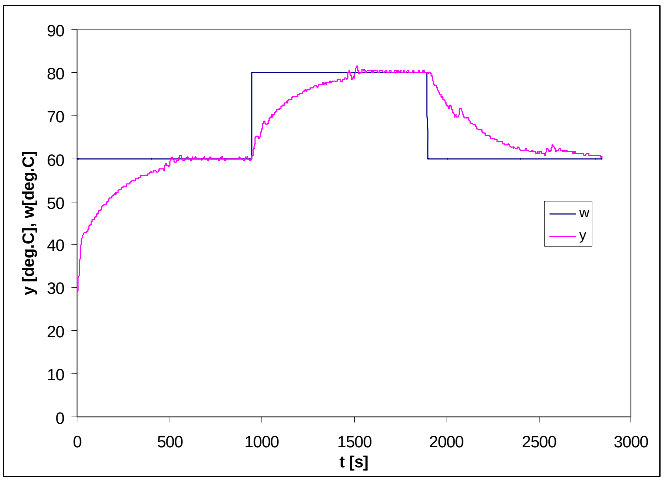

Fig.5. Heating plant model 2 control process.

$$G_{S1}(s) = \frac{k}{(T_1 s + 1)(T_2 s + 1)} = \frac{45.5}{(168s + 1)(6s + 1)} \quad (21)$$

$$G_{S2}(s) = \frac{k}{(T_1 s + 1)(T_2 s + 1)} = \frac{44.2}{(121s + 1)(7s + 1)} \quad (22)$$

5 Conclusion

This paper deals with implementation of self-tuning PID controller on low-cost 8-bit one-chip microcontroller Freescale 68HC908GB60. On the basis of described algorithms and existing program modules for adaptive control for Motorola 68HC11 microcontrollers developed at our department [3], software in assembly language was created. Its correct function was verified by controlling real laboratory heating plant models using Axiom M68EVB908GB60 development board, which is based on Freescale 68HC908GB60 microcontroller. Performed experiments indicate that modern 8-bit microcontrollers have sufficient arithmetic power to handle tasks such as adaptive control. It brings to the area of embedded systems better control quality on variety of systems.

6 Acknowledgment

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