# Microcontrollers and Modern Control Methods

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*Abstract:* - The aim of this paper is to present overview of the microcontrollers which are usable for the controllers based on the modern control algorithms. In this paper are described necessities of the self tuning controllers. In our applications, we are focused to the microcontrollers Motorola and National Semiconductor that are commonly used for process control. Microcontrollers were divided into two categories: 8-bit and 16-bit. In the part of the work dedicated to 8-bit microcontrollers, the properties of M68HC08 (Motorola) and COP8 (National Semiconductor) are described. The part, which deals with 16-bit microcontrollers, contains description of M68HC16 (Motorola) and CR16 (National Semiconductor). Finally has been evaluated CPU performance of selected microcontrollers in clock cycles needed for factorial computation.

*Key-Words:* - Microcontroller, CPU performance, 68HC08, 68HC12, COP8, CR16, adaptive - self tuning control.

## 1 Introduction

Microcontrollers today assert in all regions of human activities – beginning with applications in consumer electronics to complicated decentralized control systems, where they form particular structural members of the whole system. Progress in production technology of these very complicated circuits has lead to their miniaturization, increased central processor unit performance, decreased power consumption and decreased price. The biggest advantage of

Performance of today's modern 16 and 32-bit microcontrollers is already so high, that it is possible to create programs without any limitations in higher programming languages. Exceptions are programmatic routines that require fastest possible handling (for example interrupts from system timers and counters, communication interfaces, etc.).

On today's market we can find plenty of all sorts of microcontrollers from many worlds' manufacturers, which it is possible to use for technological process control. In this paper we are going to deal with selected types of 8 and 16-bit microcontrollers manufactured by Motorola and National Semiconductor that are frequently used in control applications.

## 2 Problem formulation

There is necessary to solve harmony between requirements of the modern control algorithms and possibilities of the hardware and software properties microcontrollers is their great flexibility in many applications. This universality is secured by possibility to program inner or outer program memory according to requirements of given application. Software equipment for 8-bit microcomputers is in most cases developed in assembly language, which is already very near one-level code. Programs created this way are very fast, because programmers can maintain optimalizations of programmed code, that compiler of higher programming language cannot realize.

microcontrollers.

### 2.1 Requirements on control system's microcontrollers

Microcontroller that we would like to utilize in process control should have following input/output units and peripherals modules:

- For technological data scanning is suitable minimally 4 channel 8 bit A/D converter with linear successive approximation. For applications with greater dynamic range of measuring signals it is necessary to use at least 10 bit A/D converter.
- Number of digital inputs and outputs is not a limitation, because majority of microcomputers with 40-pin package offer sufficient quantity. Amount of input and output ports may be further upgraded by external expander chips.
- It is necessary to choose microcontroller with largest possible internal RAM memory, because a lot of microcontrollers have no external bus for connecting standard RAM memories. Special RAM

chips can be connected through synchronous serial interfaces called SPI, MICROWIRE/PLUS™, etc. Maximum speed of serial interface and software handling limit maximum speed of these memories.

- Real time operating systems and math libraries for computing with floating point numbers have greater demands on size of program storage. Therefore internal program memory should have capacity at least 24KB. Big advantage is if this memory is FLASH type, because it considerably shortens developing time of new software.
- For safe operation of control system it is useful, if microcomputer is equipped with a watchdog system for detecting software failures. Reliability can be improved by monitoring of supply voltage (applications powered from battery or accumulator) and verification of crystal oscillator frequency.
- Control systems with self-tuning regulators mostly demand presence of nonvolatile EEPROM memory, where identified parameters from regulated system are stored. In most cases complies memory with capacity at least 128B. CMOS SRAM chip backed up by battery can completely substitute EEPROM memory.
- System timers with input capture and output compare function is required by applications with fast changes of logical levels on digital inputs and outputs. Very useful can be hardware support of pulse width modulation.

## 2.2 Adaptive control

Majority of real processes has stochastic character and their parameters can be considered constant only with higher or less degree of incorrectness. Many factors can induce change of the parameters of a process, for example change in the operating mode, different quality of the fuel or raw materials or change of the properties of the plant itself, caused for instance by aging.

Conventional controller has its parameters hard-set and therefore cannot respond to such a change of controlled process parameters. This results in degradation of the control and consequently to energy lost, decreased service life of the plant and other undesired effects.

Perspective way of dealing with these problems lays in employment of adaptive control systems, which try to copy the behavior of living organisms in the nature – their ability to adjust itself to the changing environment.

Adaptive system can be defined as a system, which measures behavior indexes of the plant, compares them with desired indexes and modifies parameters or structure of the system or generates auxiliary signal so that the measured indexes get near the desired indexes. The behavior index can be for example zeroes or poles of the transfer function, overshoot of the step function, the time of regulation, minimal values of various integral criterions or frequency spectrum.

The classification of adaptive systems is not unified yet, one of the possibilities is

- Heuristic adaptive controllers
- Self tuning controllers (STC)
- Model reference adaptive systems (MRAS)
- Systems with variable structure

**Heuristic adaptive controllers**

These controllers measure some heuristic criterion. They do not need to identify the controlled plant and often they do not require test signal or disturbance monitoring.

**Model reference adaptive systems**

These systems contain reference model, which provides exemplar characteristics. The aim is to draw the characteristics of the control system close to the characteristics of the reference model.

**Systems with variable structure**

The structure of these systems changes according to Given rules. The system changes its structure on the basis of its experience gained during previous activity so that defined results are obtained.

## 2.3 Self tuning controllers (STC)

These controllers are based on continuous estimation of controlled plant characteristics and their gradual refinement. Based on this knowledge an optimal controller is then proposed. This procedure makes it possible to catch changes in the controlled plant parameters, improve the regulation process when disturbances are present and also enables to automatically set up controller parameters.

STC controllers can be divided to implicit, which directly compute the controller parameters and explicit, which first compute the parameters of the controlled plant model and then use them to set-up the parameters of the controller. Within the scope of the above-mentioned library we dealt with STC controllers.

**The principle of self tuning controllers**

To achieve the goals of the control, it is necessary to identify the parameters of given process as good as possible. However ideal identification poses certain claims to the actuating signal and these claims differ from the claims posed on the actuating signal by ideal control. There is virtually no excitation of the controlled plant when the control is ideal and therefore the identification is imperfect. It is necessary to find such a sequence of actuating interventions so that the course of the controlled signal is as close to the reference signal as possible and at the same time the best possible identification of the process can be achieved. The general task of optimal adaptive control is very complex and for most of the real applications unusable due to its demands for computing power.

That is why this task is solved on the basis of intuition and experimental experience. This solution is known as Certainty Equivalence. Its principle is as follows:

- Parameters of the model are considered known for given step and they are equal to the estimation known in given step of the control. This estimation is naturally obtained with some uncertainty.
- Based on this premise parameters of the controller are proposed and required actuating intervention is computed.
- After obtaining a new sample of the controlled signal y(k) next step of the identification is performed using a recursive identification algorithm.

For most real-world problems this simplified technique can be used.

**The structure of STC**

The inner structure of the STC follows the above principle. The structure is depicted in Fig. 1 (Bobál, et al., 1999).

The controller consists of identification and control part, connected together only by the transfer of the estimated parameters of the system $\hat{\Theta}(k)$. Identification part carries out the estimation of process parameters and based on these parameters computes predicted value $\hat{y}(k)$ of the controlled signal y(k).

The control part contains a block for controller parameter synthesis. These parameters are computed using the estimated parameters of the controlled plant $\hat{\Theta}(k)$ and are then used to determine the value of actuating signal u(k) in each sample period. Problems in the identification for adaptive control and controllers synthesis were described in [].

# 3 Microcontrollers

## 3.1 Microcontrollers with 8 bit central processing unit

**Motorola 68HC08 MCU**

The M68HC08 is new Motorola's 8-bit industry standard flash-based microcontroller with Von-Neumann architecture. Central processor unit is fully upward compatible with the 68HC05 family. On the chip are integrated all basic peripherals such as: timer

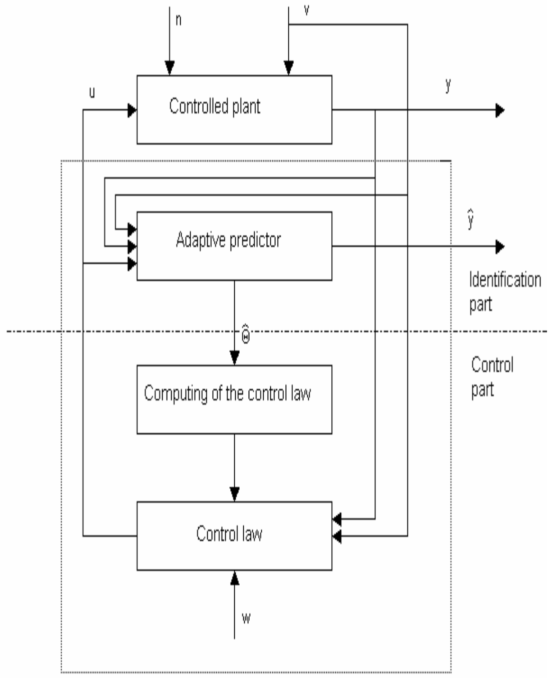



Fig. 1. Structure of the self tuning controller

interface module with input capture and output compare functions, serial communication interface with full duplex operation, serial peripheral interface, CAN module, 8 bit analog to digital converter with analog multiplexer, on chip FLASH memory with in-circuit programming capability, byte erasable EEPROM memory, watchdog system, clock monitor and low voltage inhibit functions [Motorola 2000].

**National semiconductor COP8 MCU**

The COP8 microcontrollers are based on modified Harvard architecture that supports accessing data stored in program memory. Central processor unit supports powerful bit manipulations and I/O instructions. Program memory consists of up to 32kB on chip flash memory. COP8 microcontrollers contain following on chip devices: 16 bit multifunction timers, 10 bit analog to digital converter with analog multiplexer, MICROWIRE/PLUS™ interface, full duplex USART interface, on chip FLASH memory with in system programming capability, watchdog and clock monitor [National Semiconductor 2002].

## 3.2 Microcontrollers with 16 bit central processing unit

**Motorola 68HC16 MCU**

Microcontrollers M68HC16 are based on enhanced 16-bit implementation of the M68HC11 central processor unit with digital signal processing instructions. Semi-autonomous time processor unit accelerates high-speed timing tasks without CPU intervention. M68HC16 microcontrollers have implemented a lot of internal devices such as: flexible timer system with 11 channels, phase-locked loop clock system, 8 channel analog to digital converter with selectable 8-bit or 10-bit resolution, controller area network interface, serial peripheral interface, serial communication interface, watchdog system, fast FLASH memory, SRAM modules that can be maintained [Motorola 1997].

**National Semiconductor CR16 MCU**

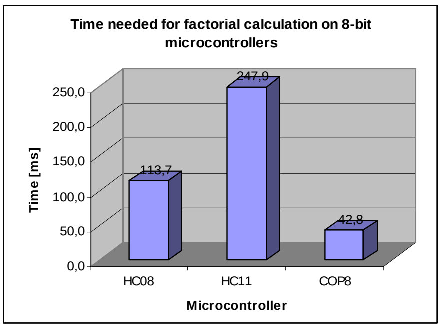
The CR16 microcontrollers have high performance reduced instruction set computer (RISC) architecture. Central processor unit uses three-stage instruction pipeline that allows execution of up to one instruction per clock cycle. Microcontroller have integrated on the chip following devices: 64KB program FLASH memory or ROM memory, 3KB of static RAM, 2KB of EEPROM memory, 16-bit multifunction timers, 2 USARTs and CAN interface, 12 channel 8-bit analog to digital converter, 2 analog comparators, watchdog system, MICROWIRE/PLUS™ interface [National Semiconductor 2002].

### 3.3 Performance test of selected microcontrollers

For each microcontroller has been created program that calculates factorial of number n. Program for 8-bit microcontrollers has been developed in assembly language, for 16-bit microcontrollers in C language. The result of this test is number of clock cycles needed for factorial evaluation. Clock cycles, which are evaluated by relevant software simulator, are then converted on the basis of nominal clock rates to time. Results of this test are shown in graphs in the Figure 2.

**Test conditions:**

- 8-bit MCUs: factorial from n=55, calculated in 256-bit integer format
- 16-bit MCUs: factorial from n=30, calculated in floating point format



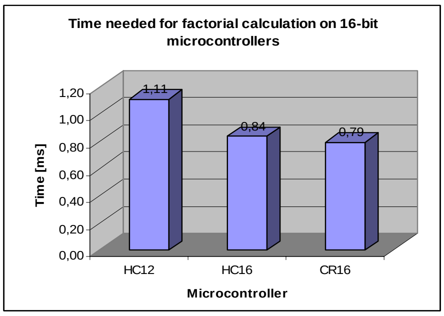




Fig. 2. Arithmetic performance of selected microcontrollers

## 4 Conclusion

New modern control algorithms such as self-tuning controllers with recursive identification or robust controllers have higher demands on arithmetic performance of used microcontroller than standard control algorithms. Therefore we performed tests that examined central processor unit performance in the basic arithmetic operations. From the test is resulting that new series of 8-bit microcontrollers have sufficient arithmetic performance for modern control algorithms. 16-bit microcontrollers are suitable for handling more control loops together.

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*References:*

[1] Doyle, J.C., Francis, B.A., Tannenbau, A.R.: *Feedback Control Theory,* Maxwell Macmillau Company, New York, 1992

[2] Prokop, R., Corruou, J.D.: Design and Analysis of Simple Robust Controllers. *Int. J. Control*, 1997, vol. 66, č. 6, 905-921.

[3] Vítečková, M. : *Seřízení regulátorů metodou inverze dynamiky*. Skriptum VŠB – Technická Univerzita Ostrava, 2000.

[4] Bobál, V. aj.: *Praktické aspekty samočinně se nastavujících regulátorů, algoritmy a implementace*. VUT Brno, 1999

[5] *M68HC908SR12, HCMOS Microcontroller Unit*, firm publication, Motorola 2000

[6] *MC68HC16R1/MC68HC916R1 user's manual*, firm publication, Motorola 1997

[7] *COP8CBR9/COP8CCR9/COP8CDR9 8-Bit CMOS Flash Microcontroller with 32k Memory, Virtual EEPROM, 10-Bit A/D and Brownout*, firm publication, National Semiconductor 2002

[8] *CR16MCS9/CR16MCS5/CR16HCS9/CR16HCS5 CompactRISC 16-Bit Reprogrammable / ROM Microcontroller*, firm publication