Programmable Specialized Controllers – a New Class for Control of Unique and Small - Batch Production Technical Objects

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Abstract: In this paper, a new class of programmable specialized controllers intended for unique technical objects is defined. This class combines advantages of embedded systems and programmable logic controllers. The organization of computational process is presented. A user-friendly programming language and its 'real time' interpreter are proposed. The debugging of user program is described. The applicability of the proposed class for control of unique and small-batch production technical objects is discussed. A control system of rotary bioreactor based on programmable specialized controllers is presented.

Keywords: programmable controllers, embedded systems, programming languages, bioreactors

1 Introduction

Industrial Control Systems (ICS) are widely used in electric power production, in control of transport, chemical, textile, engineering and food industries, as well as in experimental and research laboratory equipments. Conditionally, ICS could be classified to the following four groups [1]:

- Supervisory Control and Data Acquisition (SCADA). The aim of SCADA systems is to collect data of geographical outlying objects, to processing this information and to generate control actions;
- Distributed Control Systems (DCS). DCS systems generally consist of two levels. At lower level separate subsystems realize local control of objects. The higher level is responsible for tuning, coordination of connections of included subsystems and for full production optimization;
- Programmable Logic Controllers (PLC) [6]. PLC are microprocessor devices controlling industrial equipments and/or processes directly. PLC have wide application in automatization of all industrial processes of both continuous and discrete production;
- Embedded systems (ES) [3]. ES are control systems with high degree of hardware and software integration, closely connected with controlled equipment or embedding system.

Regardless of their applicability to control of small technical objects micro PLC и ES have the following disadvantages:

- The development of unique devices and/or small-batch production using ES requires highly skilled hardware and software labour. The debugging of the application software has to be realized by programmer being skilful at low level programming languages (assembler). This leads to the impossibility ES to be developed by specialist in technology and could has a negative effect on the product;
- In PLC there are not possibilities for measurement of some specific quantities as well sufficient resources in their programming language to be used for complex control algorithms development.

In this paper, a new class of controllers is proposed. These controllers combine the advantages of PLC and ES and avoid some problems engendered from application done on PLC and ES own for control of unique and small-batch technical objects.

2 Programmable Specialized Controllers

Programmable specialized controllers (PSC) could be characterized as:

- Small (up to 40 inputs/outputs) controller systems with limited hardware resources;
- According their hardware characteristics (fixed number and types inputs/outputs, fixed power supply parameters including non-standard ones), fixed communication channels, PSC are identified with ES;

- According to development of system software (only once developed, unchangeable during the process of development, tuning and exploitation of user programs) PSC are identified with both ES and PLC;
- In accordance with user program development (multiple editing, loading, debugging system) they are identified with PLC;
- In accordance with their exploitation (fixed hardware, unchangeable during all cycle of life process user programs), PSC are identified to a great extent with ES, but also as PLC.

All above - mentioned characteristics could be summarized in the following definition of PSC:

Programmable specialized controllers are small control systems with unique hardware, standardized system software, high level user programming language and a possibility for multiple loading and debugging of the technological program.

PSC take intermediate place between ES and micro/small compact PLC. The connection via serial channel to upper level allows multiple user programming and debugging as well using of personal computer for visualization, archiving, recording of controlled process. An additional possibility is the work of PSC in local net with others PSC, intelligent terminals and personal computers.

The hardware and system software of PSC are developed by experts, but application software can be realized by technologists (chemists, physicists, engineers, etc) familiar with the controlled object. It is an advantage as far as contemporary projects are interdisciplinary and territorially outlying ones. PSC reduce developing process time thanks to high level programming language, debugging system of user program and the possibility technologists to develop and debug the application software unassisted.

The application of PSC compared with ES and PLC is showed on Fig.1.

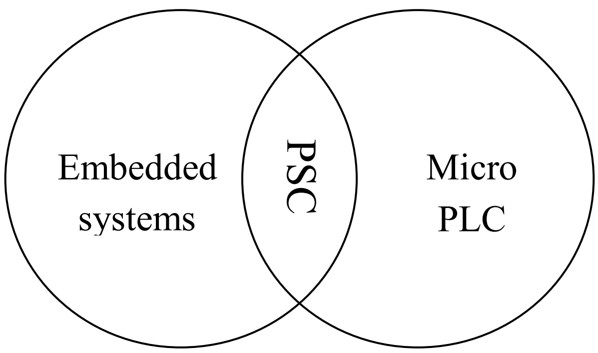

Fig.1. Application of PSC compared with ES and PLC

PSC are directed to both industry and laboratory applications due to their capacity of control of unique and small-batch production objects as prototypes, scientific experiments, etc.

The organization of computing process in PSC is similar to that in PLC and is presented in Fig. 2.

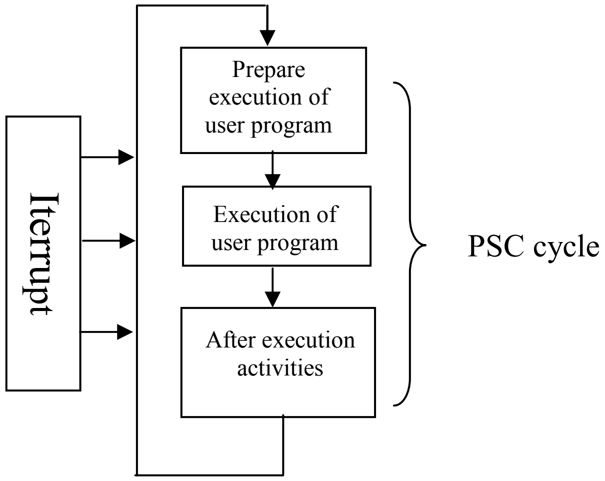

Fig.2. The organization of computing process in PSC

3 Development of application software for PSC

The developing tools for application software include universal procedure language, its translator as well as system for loading and on-line debugging.

The universal language for application software of PSC (ULAS) is a high level procedure language, oriented to specific tasks realized by PSC. It allows direct or indirect work with inputs and outputs of controller, logical data processing, assign of value of variables, arithmetical operations including floating point, unconditional and conditional branches.

ULAS considers the basic microcontroller as virtual three-address von Neumann machine. The structure of one instruction is as follows:

<code of operation> <operand 1> [<operand 2>] [<operand 3>]

As can be seen, each instruction consists of code of operation and at least one operand. The code of operation shows what relation has to be realized among operands in the instruction.

The data types in the language are:

- Discrete inputs - I - from I1 to I24. They take values 0 or 1;
- Discrete outputs - O - from O81 to O96. They take values 0 or 1;

- Logical variables - B - from B1 to B128. They take values 0 or 1;
- Decimal variables - D - from D1 to D104. They take integer positive values from 0 till 9999;
- Timer variables - T - from T1 to T24. They can realize time delay from 10 msec till 99,99sec.;
- Constants - C – integer decimal value from C0 to C9999;
- Labels - L - from L0 to L511.

The data types are presented in instructions of language as operands. The name of each variable consists of variable identifier (I, O, B, D, T, C, L) and number.

Each instruction of ULAS consists of code of operation and at least one and maximum three operands. Eighteen main types of instructions are introduced and their total number with modifications is 80:

- Outputs updating – code of operation OUT. The value of the first operand goes to output;
- Inputs reading - code of operation INP. The input value is assigned to the first operand;
- Assign a value - code of operation LDU. The value of the second operand is assigned to the first operand;
- Logical negation - code of operation NOT. The inverse value of the first operand is assigned to the second operand;
- Logical "OR"("AND") - code of operation OR(AND) . The function is realized between the first two operands and the obtained result is written into the third one.
- Integer addition, subtraction, multiplication and division - code of operation ADD/SUB/MUL/DIV. The arithmetical operations are realized with integer positive numbers. The function is carried out between the first two operands and the obtained result is written into the third one. Under these instructions a flag ”carry”/”borrow”/”overflow” is manipulated in different way depending on the type of instruction.
- Increasing/decreasing of the value of decimal variable with 1 - code of operation INC/DEC;
- Instructions for control of program flow – unconditional and conditional branches in data values (flag ”carry”) in the first operand, including "computable goto". Codes of operation: BRA/BCS/BCC/BEQ/BNE;
- Setting of label - unexecutable instruction. It marks with label L next operator. Code of operation LBL.

The special variables in ULAS are interface between system and application software and are part from B- D- и T- variables. By means of them the core and drivers of operating system exchange on-line data with application software that are necessary for correct realization of technological algorithm.

A combined untraditional approach is chosen for developing of the translator for ULAS. It is conditioned by limited resources of PSC. The translator is divided to two independent modules working in different environments. Resource intensive part, including lexical, syntax analysis and generation of code of output text of user program is realized on personal computer, working under Windows XP/Vista/7. In fact this is 'offline' cross compiler of virtual machine working with pseudocode. The generated code is processor-independent that allows it to be realized on different processors. The downloading of so compiled pseudocode is carried out via serial channel into flash memory of the microcontroller. An exemplary instruction of ULAS in output (text) form and its equivalent pseudocode is presented below:

```
LDU  T15  C1000      load 10.00sec into timer15
0C   OF   03E8       pseudocode (hex)
```

The processor-depended part of the translator is developed on the target processor and represents interpreter of so generated pseudocode. The lack of necessity from lexical and syntax analysis increases repeatedly fast response of application software. Furthermore in this way the memory necessary for realization of bigger user programs is decreased.

The system for downloading and on-line debugging (SDOD) is responsible for compilation, downloading and debugging of user programs. SDOD works on personal computer under operating system Windows XP/Vista/7. Its main functions are:

- Compilation of program, written using ULAS into pseudocode;
- Downloading of pseudocode in PSC via serial channel;
- Choice of mode of execution of user program – continuous or stepwise;
- Choice of stopping of execution of user program – with or without retention of variables states;
- Choice of variables for observation and/or change during execution of user program;
- Upload of pseudocode from PSC and its decompilation to user program.

By means of SDOD all interface and internal controller's variables can be monitored and updated. This system is connected to PSC in serial channel

RS232 (Com1, Com2 … Com8) and has intuitive interface. The main screen of SDOD is shown in Fig. 3.

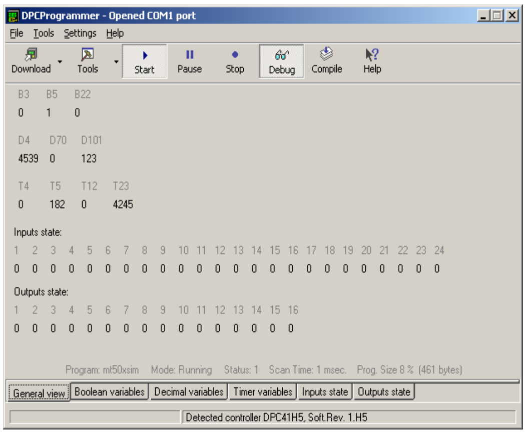

Fig.3. Main screen of SDOD with chosen and modified variables

4 PSC control of rotary bioreactor

Tissues and cells cultivated in bioreactors are widely used in medicine and biology for patient transplants, investigation of influence of pharmaceuticals, genetic engineering, etc. In the bioreactors have to be maintained optimal physic-mechanical conditions for cell's reproduction leading to cell culture with the specific properties and a quality of the original tissue. The experiments carried out in space stations of NASA and Russian "Mir" show that in conditions of weightlessness the mammals tissue cultures growth much better than in earth conditions [2]. The necessity of high quality tissues cultivation imposes new methods for simulations of weightlessness conditions (micro gravitation) on the earth to be proposed. That could be reached by:

- Movement of bodies with acceleration close to acceleration of gravity;
- The action of other forces on the bodies (for example hydraulic or electromagnetic ones) which balance the gravity.

For the present the most widespread method for simulation of weightlessness conditions is based on the bodies submerging in liquid environment using bioreactors with rotating vessel. Dependence of the sedimentation on size of cell culture enforces control of reactor rotation speed. The control of the speed with unevenness during one revolution would mask some unfavorable effects – sedimentation, centrifugal effect, etc. [2].

PSC is applied for solving of similar tasks. A prototype of rotary bioreactor with unevenness speed control is developed in ISER-BAS [5, 8] and successfully implemented in Biotechnological Laboratory-Medical University Sofia.

The structure scheme of PSC is shown in Fig. 4. In Fig. 5, picture of bioreactor, PSC and power module are given.

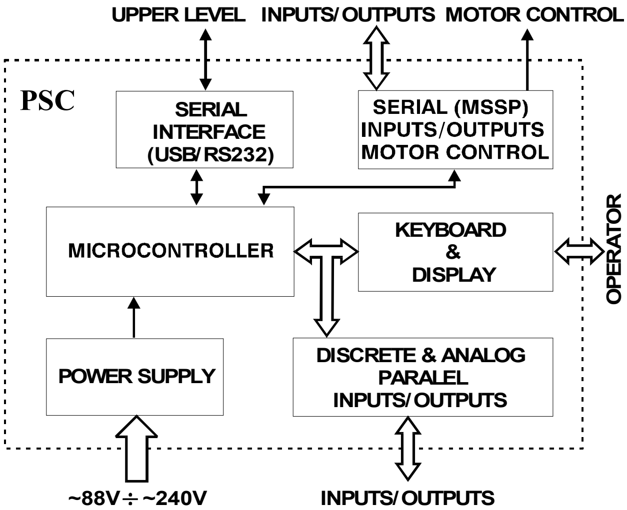

Fig. 4 Structure of PSC for control of rotary bioreactor

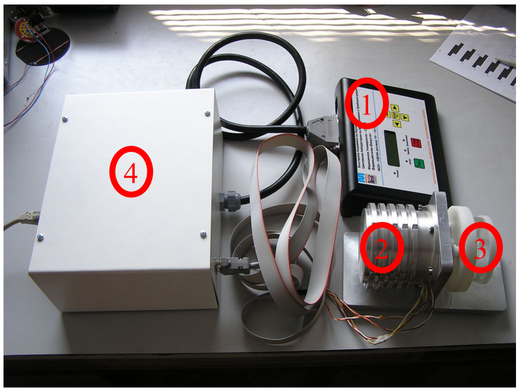

Fig. 5 Rotary bioreactor with PSC control.

PSC can work in two main modes. The first one is on-line. At each stage of the process standard laws for change of reactor rotation speed could be set from expert's point of view. Stepper motor is used in this rotary bioreactor. Its speed, S_k, for every stage, k, is calculated by the following formulae:

$$S_k = A_k + B_k \sin(C_k t),$$

where $k \in [1,9]$, integer; A_k is offset of sinusoidal wave; B_k – amplitude and C_k – period. The duration of every stage, T_k, is set by the operator also.

The parameters of the law are set up by the operator - biologist from the control panel of PSC.

The second mode gives a possibility more complex laws for change of reactor rotation speed to

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be applied. They are developed previously by specialized programs (LABVIEW, MATLAB, etc.) on personal computer, prepared as control table data and downloaded via serial channel into flash memory of PSC. Running the program in PSC it automatically executes the movement algorithm guarantying growth of cell and tissue cultures.

The controller works autonomously – without upper level. The autonomous action of bioreactor consists of: the programming of bioreactor vessel movement from control panel, starting, pause and stopping of program execution. After power falling and subsequent supply voltage recovery PSC automatically renews the bioreactor movement.

5 Conclusion

The class controllers proposed in this paper as well as their programming language and debugging system facilitate and reduce the user program development time. The above mentioned application as well as others similar ones show the effectiveness of proposed controllers [4, 7, 9].

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