Universal DAQ microcontroller unit: Evolution II

Petr Dostálek and Libor Pekař

***Abstract*—**Hardware design, software equipment and the functionality of the second evolution of the intelligent multipurpose input/output microcontroller converter and control unit is the goal of this contribution. Preceding stages of the unit development are concisely overviewed first. Then separate hardware parts are described in details including electronic schematic diagrams. The device firmware and software capabilities are introduced as well. User-related functionality issues are then provided to the reader followed by a concise measurement example. In the contrary to previous evolutions, a more compact hardware design, increased A/D and D/A converter resolutions, added USB communication capability, better and more accurate analog circuits with more advanced operation amplifiers, the use of OLED instead of LCD display, the pulse-width modulated signal generated by the microcontroller unit itself can be considered among the most important improvements. Moreover, the direct use of the serial link may reduce noise significantly.

***Keywords*—**Data acquisition card, engineering education, microcontroller unit, temperature control.

I. INTRODUCTION

Heating and temperature measurement and control modules represent one of the most common laboratory appliances in the computer and engineering educational process [1]-[3]. Among the main reasons for that, temperature of a quite wide values range can easily and non-expensively be measured and processed, heating plants are sufficiently slow and their model are usually not very complex such that students can simply design a controller, and from the practical point of view – temperature control is pervasive in industry [4]-[7].

Hand in hand with that, signals and data ought to be processed and evaluated via data acquisition units (DAQ), converters and computers [3], [4], [8]. In addition, hardware (HW) devices have to be equipped with proper firmware and ad-hoc or general-purpose software (SW) [7], [9].

Dealing with the educational process in subjects related to automation and control at home institution of both the authors, we designed and developed a simple and smart compact modular low-cost microcomputer input/output (I/O) laboratory module for signal converting, data acquisition and control of a temperature educational plant to replace an obsolete unit [3]. However, some problems and imperfections with this first evolution of the innovated converter unit persist, and thus a redesign has been desirable.

This paper is aimed at the description of the design of the second evolution of the device bringing new useful features. The rest of the paper is organized as follows: Section II provides the reader with design history overview. HW and SW equipments of the designed unit are described in sections III and IV, respectively. Prior to conclusion, the device functionality is verified by step response measurement in section V.

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic within the National Sustainability Programme project No. LO1303 (MSMT-7778/2014).

P. Dostálek and L. Pekař are with the Department of Automation and Control Engineering, Faculty of Applied Informatics, Tomas Bata University in Zlín, Nad Stráněmi 4511, 760 05 Zlín, Czech Republic (e-mail: {dostalek, pekar}@fai.utb.cz.

II. PRECEDING EVOLUTIONS OVERVIEW

Since the eighties of the last century, every single seat in the laboratory room was equipped with a central PC with Advantech PCI 1171 acquisition card connected to the I/O converter and control unit (see Fig. 1) which serves as an interface between the PC and the controlled plant. The appliance has, however, suffered from some deficiencies which have disabled to keep using it for present and future modern control and identification teaching tasks. Moreover, it has been powered by 230V AC from mains, which does not meet current working and safety conditions. Two built-in converter cards for signal processing from Pt100 sensors, have provided the user with the normalized analog signal within the range of 0-10V DC. A rheostat in the heating plant body has been warmed up by 24V AC control input.

In 2014, a modern modular unit prototype was designed and assembled [1], see Fig. 2 for its appearance and Fig. 3 for the functional block scheme. This innovation has brought the preservation of basic functional properties of the obsolete appliance, and improved many other attributes; namely, the unit has been powered by the safe 24V AC input, equipped with a central microcontroller board, LCD display, a 3x3 keyboard and the RS232 interface.

Fig. 1 the appearance of the former obsolete I/O converter and control unit

Fig. 2 the appearance of the first evolution of the module – the front (up) and the back side (down)

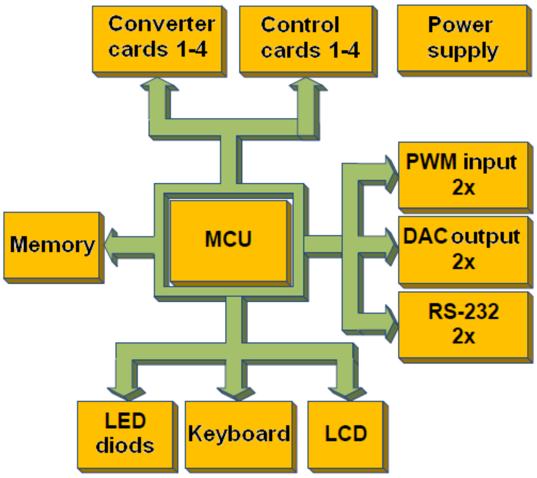

Fig. 3 a block scheme of the first evolution of the module

A firmware implementing basic input and output functions, diagnostic and peripheral services has been developed in addition, the serial interface can cooperate e.g. with MATLAB©. The unit has a modern appearance, is compact, intelligent and safe and can be easily modularly extended. Among other crucial benefits of this first evolution is its prize: Components and manufacturing on the designed device costs about 350$ in total.

There have been, however, still many features that might be improved, for instance, the unit would have processed a general unified electrical signal, such as 0-10 V DC, which may help to extend the area of its applicability, and there have been a relatively high noise and low measurement accuracy levels. The modularity of this evolution of the unit can also be better. Hence, a second evolution has been designed and the prototypal appliance assembled – its basic description follows.

III. Converter Unit Hardware

Hardware design of the intelligent converter unit device for resistance temperature sensors evaluation is adapted to high accuracy and easy functionality expansion in future applications by simple adding of measurement modules with required features. Additionally, it is capable of generating power control signal which can directly drive heating elements, for example. This is achieved by splitting the converter unit into the two basic parts:

- The main board consisting of the master microcontroller (MCU), communication interfaces (COM), stabilized power supplies (PSU) and expansion connectors for input and output modules.
- Expansion modules which will be inserted into the connectors of the main board. Basically, two types of modules can be implemented: input modules converting analog signals from sensors to digital signals and output modules converting digital signals back to analog ones.

A scheme of basic blocks introduced above can be seen in Fig. 4.

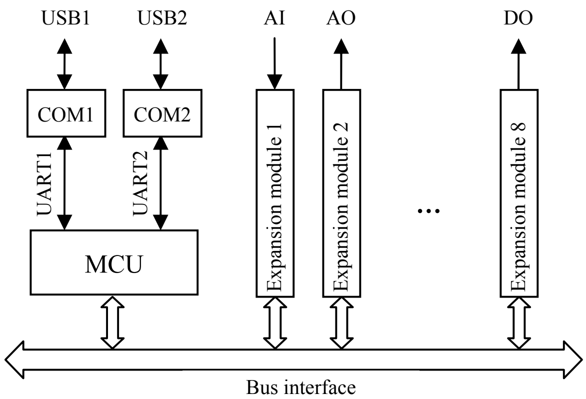

Fig. 4 block schematics of the intelligent converter unit

A. *Main board design*

Main board design is based on Freescale MCF51AC128 microcontroller [10] in the QFP64 package performing all operations of the intelligent converter unit. It is a member of Flexis 32-bit ColdFire® V1 microcontrollers' family enabling simple migration from 8-bit Flexis MCUs to 32-bit due to pin-to-pin compatibility. They are suitable for entry-level applications that do not need special features of ColdFire V2 core. Internal program loading and debugging is provided by on-chip Background Debug Module (BDM).
MCF51AC128 main features are:

- 128 KB of flash memory
- 32 KB of static RAM
- 1x Serial Peripheral Interface (SPI)
- 2x Serial Communication Interface (SCI)
- 1x Controller Area Network (CAN)
- 1x Inter-Integrated Circuit (IIC)

- Flexible Timer Module 1 (FTM1) with 6 channels
- Flexible Timer Module 2 (FTM2) with 2 channels
- Timer Pulse-Width Modulator (TPWM) with 2 channels
- 54 general purpose I/O pins (16 pins shared with rapid GPIO (General-Purpose Input Output)
- 12-bit Analog-to-Digital Converter (ADC) with 20 analog channels
- Single-wire background debug interface

The correct program function is monitored by an integrated watchdog Computer Operating Properly (COP) system and illegal operational code and address detection with programmable reset or exception response. The Central Processor Unit (CPU) can work at the frequency up to 50.33 MHz, the maximum internal bus frequency is 24 MHz at the 2.7 to 5.5V supply voltage range.

The communication with higher control or supervision systems is provided by two FT232BM USB Universal Asynchronous Receiver/Transmitter (UART) Integrated Circuits (ICs). They are capable to communicate at TTL levels with data transfer rates up to 3 MBd. An on-chip integrated transmit and receive buffer with capacity of 128 B and 384 B enables high data throughput. FT232BM operates from the single power supply with voltage of 5 V. The USB I/O interface is supplied from an integrated 3.3V voltage regulator. Due to the integrated level converter for UART I/O signals it is possible to connect it with logic circuits operating at 3.3 V or 5 V. Both communication interfaces are realized in a manufacturer recommended wiring for a self-powered application with the 5V input/output interface. A connected EEPROM memory 93C46 is optional and can be used for storage of USB Vendor Identification (VID), the device class definition for Physical Interface Devices (PID), serial number and product description strings. The clock signal is generated externally by a crystal oscillator with frequency of 6 MHz. USB1 and USB2 UART I/O interfaces are connected to corresponding UART0 and UART1 pins of the main microcontroller.

Expansion modules can be inserted into eight 30pin double-row connectors including all necessary signals for their function. They provide all available voltage sources: 5 V for digital and +15 V, -15 V DC for analog circuits, the serial peripheral interface for communication with the master microcontroller and finally an 8 input and 8 output general purpose digital interface which can be utilized for internal logic control of the connected modules. The active expansion connector is selected by the main microcontroller in the cooperation with a 3-to-8 line decoder 74HC138 on which outputs eight board select signals (active at the low logic state) are available. Only one expansion module can be in active state at the moment and it communicates via the SPI interface

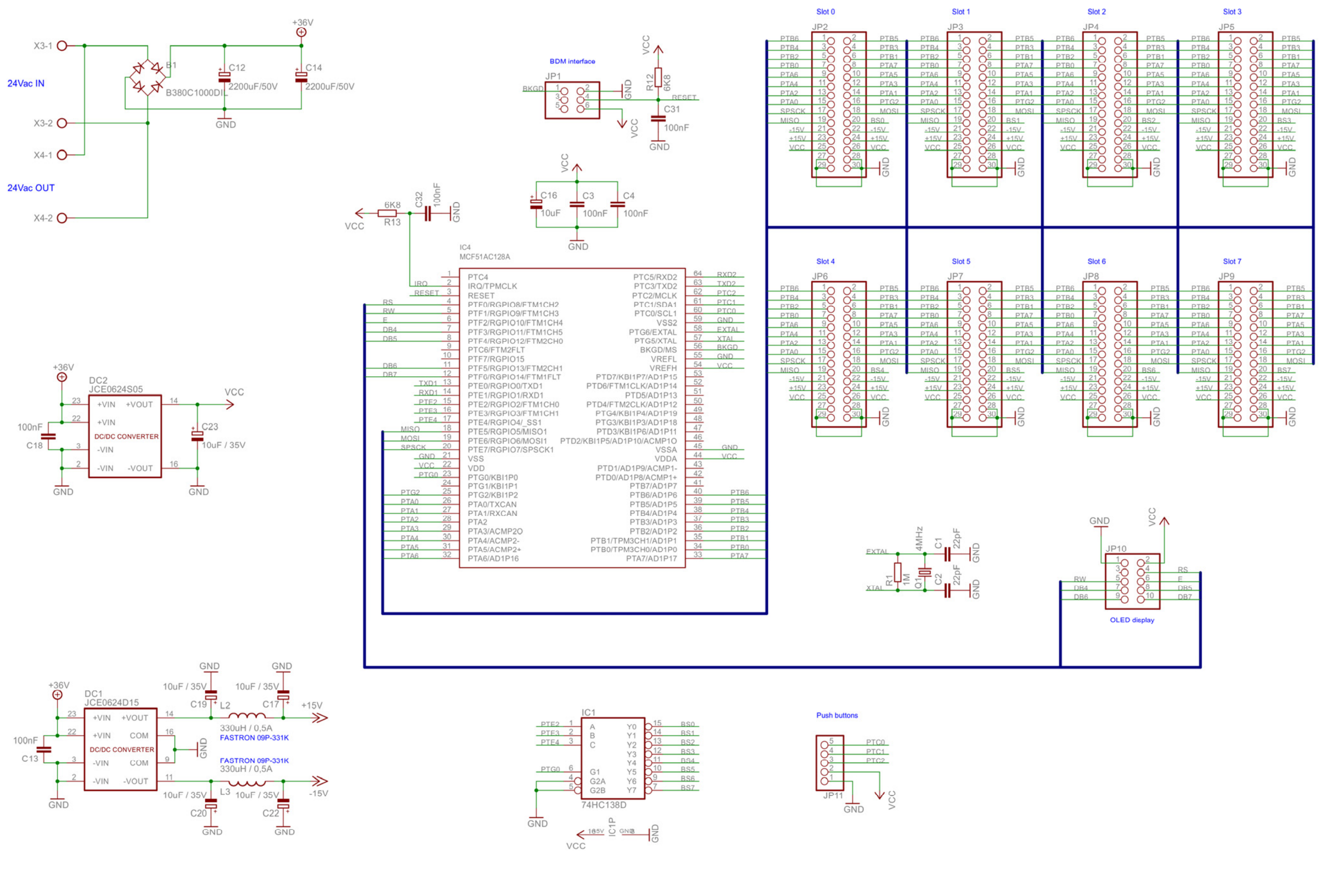

Fig. 5 Schematic of the mainboard – part 1: main microcontroller, power supplies, expansion connectors

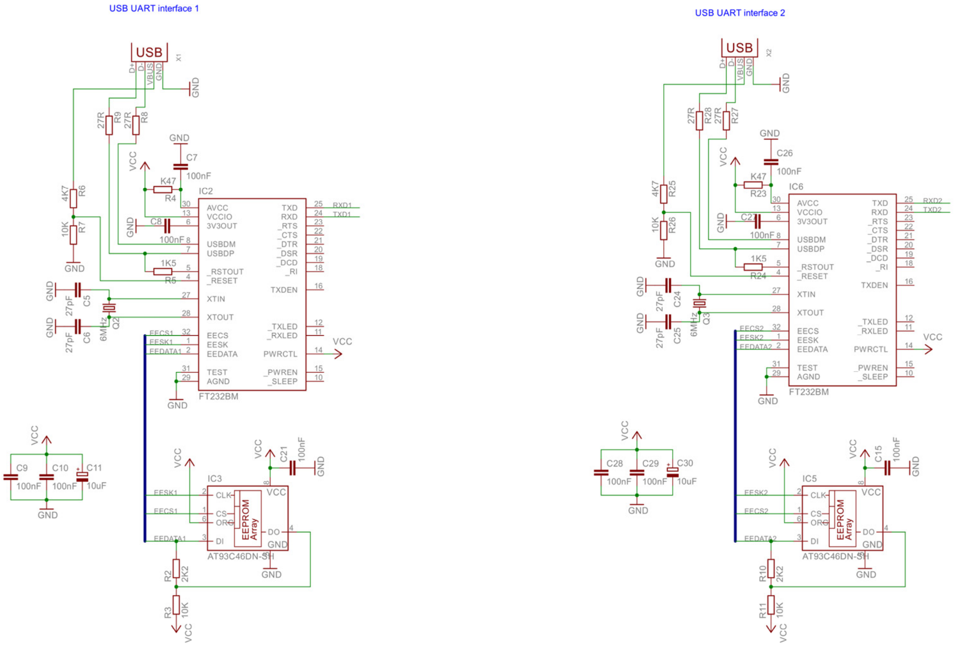

Fig. 6 Schematic of the main board – part 2: USB UART interfaces

with the microcontroller. Other modules must stay in the high impedance state.

Main board also provides parallel interface for OLED display control consisting of 4 data lines (DB4 – DB7), 3 control signals (RW, RS, E) and +5 V power supply lines.

The main board is supplied from a 24V AC voltage source which is commonly used in control systems for sensors and actuators power supplies. A rectified input voltage is converted by two DC-DC converters to 5 V with the output power of 6 W for logic circuits and ±15 V for analog circuits. Schematics of the main board are depicted in Fig. 5 and Fig. 6.

B. *Expansion modules design*

The converter unit hardware configuration is determined by installed expansion modules. Each module type has its identifier which can be read by the main microcontroller from the bus interface. During the initialization phase all expansion slots are scanned and connected modules auto-detected and correctly initialized.

The following modules are currently available:

- Analog and digital inputs
- Analog outputs
- Power digital outputs

1) *Analog and digital inputs module*

The module is equipped with two analog converters for Pt100 type resistance temperature sensors with range from 0 to 400 °C and two voltage analog inputs with unified range from 0 to 10 V. All analog inputs are protected against voltage overload by protection diodes. Analog signals are converted by using the 14-bit analog-to-digital converter TLC3544DW to digital values which are transferred by a SPI to the main microcontroller. High temperature stability of analog circuits is achieved by the utilization of precision operational amplifiers OPA4277. The reference voltage of 3 V for analog and digital circuits is provided by the voltage reference IC AD780ANZ. A bus interface of the module is controlled by two octal 3-state bus transceivers 74HC245.

Module parameters:

- 2x analog input for Pt100 resistance temperature sensors, 4-wire configuration, 1mA constant current
- 2x analog input from 0 to 10 V
- 2x TTL compatible digital input
- 14-bit analog-to-digital converter resolution

Schematic of the analog and digital inputs module is depicted in the Fig. 7.

2) *Analog outputs module*

The module is based on two 16-bit digital-to-analog converters DAC8830 with a SPI communication interface. Output of the converter is amplified with a non-inverting amplifier with the gain of 4 resulting in the final output voltage range from 0 to 10 V. High temperature stability of analog circuits is achieved by utilization of precision operational amplifier OPA2277PA again. The reference voltage of 2.5 V for digital-to-analog converter is provided by the same voltage reference as for the module of analog and digital inputs.

Module parameters:

- 2x analog output with the range from 0 to 10 V
- 10mA output current per channel
- 16-bit digital-to-analog converter resolution

Schematic of the analog outputs module is depicted in the Fig. 8.

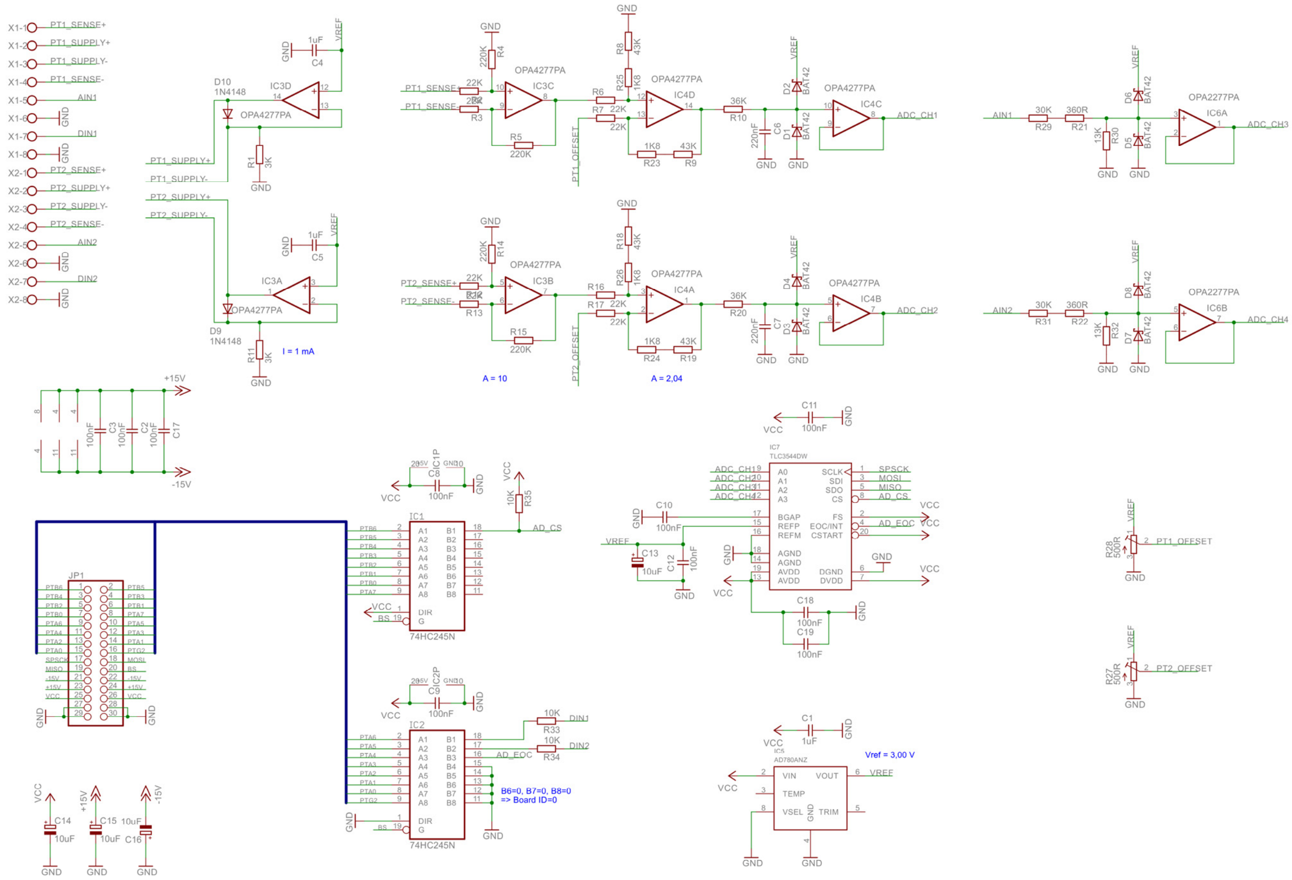

Fig. 7 Schematic of the analog and digital inputs module

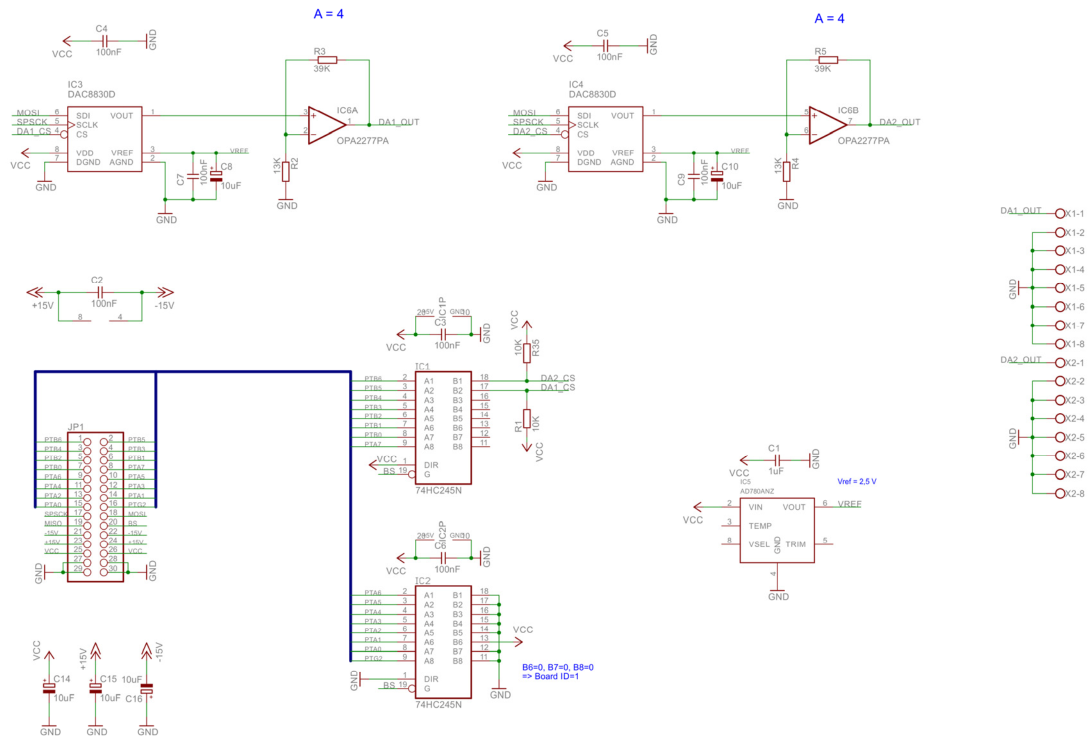

Fig. 8 Schematic of the analog outputs module

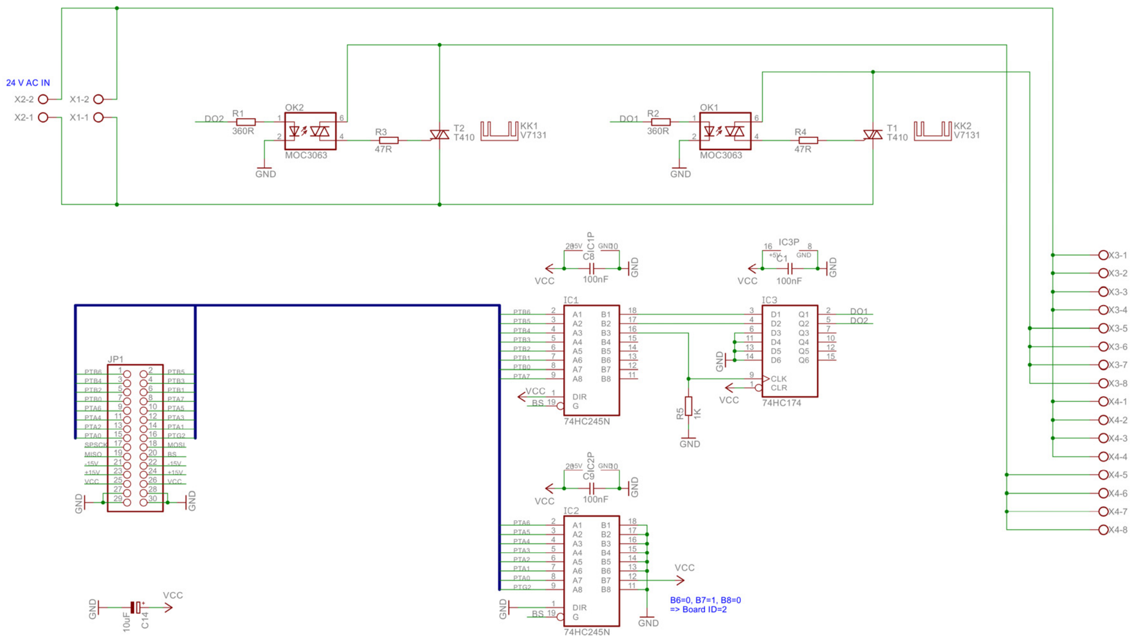

Fig. 9 Schematic of the power digital output module

3) Power digital outputs module

The switching of the two resistance loads with the power supply voltage of 24V AC is the main function of this module. It utilizes power triacs T410 which are separated from sensitive digital control circuits by optotriacs MOC3063. Power triac T410 is capable to handle current up to 4 A RMS with small turn-on gate current of 10 mA enabling its control using standard TTL logic. Its maximum operating voltage is 600 V. Control signals for triacs are generated by the D-type flip-flop 74HC174 in which the main microcontroller desired value of the corresponding digital output is stored. A bus interface of the module is controlled by transceivers of the same type as for the analog and digital inputs module.

Module parameters:

- 2x power digital output 24 V AC
- 2.5 A output current per channel

Schematic of the power digital output module is depicted in the Fig. 9.

The overall external appearance of the developed converter unit is pictured in Fig. 10. There can also be seen the 4-line alphanumeric OLED display WEH002004A and a simple 3-key board with yellow backlight for moving in the menu, confirmation and cancellation in the figure.

IV. Device Firmware and SW

Converter device firmware was written in Freescale CodeWarrior for microcontrollers integrated development environment in C language with utilization of Processor Expert peripheral components. Software consists of the two parts: main program routine and interrupts service routines.

A. Main program routine

Main program routine is started after power-up of the converter unit. First of all is executed Procesor Expert function PE_low_level_init() which initializes CPU, all used hardware components and corresponding internal data structures. After this initial initialization user program is executed. It must first detected source of the system restart. If it was power on reset (POR) OLED display hardware is initialized otherwise this step is skipped because it was already initialized. Then follows expansion board detection process during which internal data structures are updated and all boards are prepared for correct function. If any error occurred or wrong configuration is discovered during this phase, device is halted with corresponding error message on the display.

After successful startup sequence information welcome text and firmware version is displayed for two seconds. Next program code run in infinite loop in which following operations are sequentially treated:

- Process user input from keyboard
- Display required data
- Compute actual PWM duty for digital outputs
- Process commands from both serial interfaces
- Write computed values to outputs

B. Interrupt service routines

Interrupt services handle events originating in peripheral modules of the main microcontroller. Firmware implements three interrupt handlers: timer interrupt with period of 1 ms where data acquisition and filtering task are processed; serial interface 1 and 2 interrupt which occurs when one character from the supervisory system is received.

V. Functionality Test

In order to verify the functionality of all HW parts and modules of the designed device its elementary firmware the measurement of dynamical (step) responses was performed. Two types of experiments were made; as first, the mean output power generated by the 24V DC PWM signal is successively increased in steps, whereas the second stage resides in the abrupt power decreasing. Graphical results of such an experiment are provided in Fig. 11.

Fig. 10 The appearance of the second (new, herein described) evolution of the module – the front (up) and the back side (down)

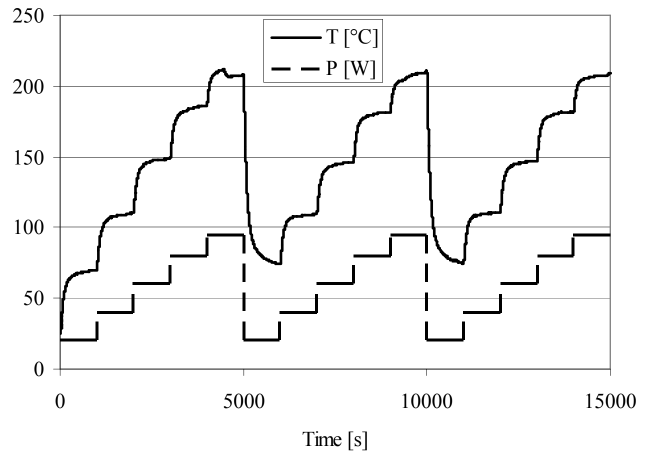

Fig. 11 The measurement of step responses by means of the new I/O converter and control device

VI. Conclusion

This paper has been focused on the description of the second evolution of the innovated I/O data acquisition, converter and control for laboratory measurement on heating models which can be also used as a multipurpose device. The basic characteristics, desirable features and main improvements are the following: Crucial features of the preceding design has been preserved; an innovated HW structure – the motherboard including the microcontroller, 2x USB communication interface, a power supply and 8 connectors for expansion modules, A/D converter resolution increased to 14 bits, D/A converter resolution increased to 16 bits, more accurate operation amplifiers mounted on analog circuits, the USB interface enabling the better compatibility with notebooks (laptops) compared to RS232 without the necessity of an external USB to RS232 converter, significantly reduced noise due to the direct serial link, the OLED having much better readability, response and energy consumption compared to LCD with LED backlight; new useful functions - a four-line LCD panel, buttons allowing calibration of the I/O channels with saving, the RS232 interface for serial communication with PC. The significant advantage of the device can also be seen in its low price, which has made the unit easily reachable for a wide range of potential users.

References

[1] D. Mahoney, B. Young, and W. Svrcek, "A completely real time approach to process control education for process systems engineering students and practitioners," *Comput. Chem. Eng.*, vol. 24, pp. 1481-1484, 2000.

[2] S. Postalcioglu, E. D. Bolat, and K. Erkan, "Temperature control using autotuning PID controller for control education," in *Proc. WSEAS Int. Conf. Signal Processing, Robotics and Automation*, Madrid, Spain, 2006, pp. 131-134.

[3] L. Pekař, P. Dostálek, P. Navrátil, and Z. Oborný, "Low-cost intelligent educational laboratory temperature data acquisition and control device," *Int. J. Circ. Sys. Signal Pr.*, vol. 9, pp. 103-112, 2015.

[4] G.-Q. Liu, "A temperature-measuring system on the gun-barrel bore of armor-artillery base on 80C196 MCU," *Adv. Mat. Res.*, vol. 562-564, pp. 1920-1923, 2012.

[5] P. Doležel, V. Vašek, D. Janáčová, K. Kolomazník, and M. Zálešák, "Modeling and microcontroller control of raw hide soaking in tannery industry," *Int. J. Math. Mod. Meth. Appl. S.*, vol. 5, no. 7, pp. 1225-1232, 2011.

[6] S. Plšek and V. Vašek, "The control system for the production of biodiesel," *Int. J. Circ. Sys. Signal Pr.*, vol. 6, no. 5, pp. 342-349, 2012.

[7] M. Staněk, D. Maňas, D. Maňas, J. Navrátil, and A. Škrobák, "SW and HW optimization of injection molding process," *Int. J. Mech.*, vol. 8, no. 1, pp. 85-92, 2014.

[8] P. Dostálek, V. Vašek, and J. Dolinay, "Simple microcontroller based mains power analyzer device," *Int. J. Circ. Sys. Signal Pr.*, vol. 7, no. 4, pp. 214-221, 2013.

[9] J. Dolinay, V. Vašek, and P. Dostálek, "Utilization of simple real-time operating system on 8-bit microcontroller," *Int. J. Math. Mod. Meth. Appl. S.*, vol. 5, no. 7, pp. 785-796, 2011.

[10] *MCF51AC: Flexis 32-bit ColdFire® V1 Microcontrollers* (cited 2014, August 25), Freescale Semiconductor, Inc. [Online]. Available: http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MCF51AC.