Digital Control for the Air Pressure with Multi-Characteristics Selection

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***Abstract* - The paper deals with a preparatory research stage for controlling the air pressure inside a small tank by various characteristics and algorithms. Basic elements both for the hardware design and for the software support are presented. The experimental platform brings together parallel solutions: a microcontroller board using a PIC™ 16F877 chip from Microchip and an industrial controller from Honeywell™. The functionality of the platform will be tested in this stage by the on-line commutation of the control characteristics IN (pressure error) – OUT (PWM control for the air pump). A set for the available characteristics of the controller is stored in software. For a fast design with simulation and debugging capabilities, the author used Flowcode™ of Matrix Technology Solutions - an Integrated Development Environment with a Very High Level Programming Language. Future research works are intended for some fuzzy control algorithms that could adapt and optimize the control accordingly the dynamic of the process. The main components of the platform are, besides the controllers mentioned above, an industrial pressure sensor, a compressor, the pressurized container and some standard pneumatic devices for a safe operation. Both the hardware and the software design are made so that besides the research aims, the platform could be a flexible and multi – purpose didactic tool for the students.**

Keywords: *digital control, air pressure, characteristics selection.*

I. INTRODUCTION

The impact of the digital control solutions in the area of pneumatic systems is more and more obvious during the last decades. If many years ago most of (industrial) applications of microcontrollers concerned the motion control field and the temperature control, now many studies and products integrate microelectronics for different kind of fluidic systems. Ref. [13] makes a synthetic comparison of pneumatic and Direct Digital Control (DDC) in terms of: performance - best DDC, initial cost – comparable, reliability, maintainability, flexibility, easy of use, life cycle cost, cost, management , proprietary – best pneumatic. An analyze of the air compressor production process, as a time-varying, delay and nonlinear complex system, is included in [5]. In order to avoid the drawbacks of classical control systems, affected by pressure instability, a fuzzy pressure controller and an intelligent control method based on the fuzzy PID were proposed.

Many studies and solutions are associated now with the Tire Pressure Monitoring Systems (TPMS) - devices and systems, because the associated equipment became a compulsory one for the new models in automotive. In this meaning, temperature and pressure sensors values are taken and processed on Programmable System on Chip (PSoC) controller and transmitted via Bluetooth on dashboard or to a smartphone [1]. Using PsoC is possible to minimize the size and power consumption of the system. The main goal in some research works is the power management, considered in [6] to be an important aspect in designing battery operated TPMS as it helps to prolong the lifespan of the battery. The implementation of SLEEP mode to minimize power consumption is discussed and the currents consumed by the microcontroller in SLEEP and ACTIVE modes are measured and recorded. The main tools (hardware and software) belong to the well known producer Microchip (PIC™ microcontroller, MPLAB™). An extra study concerns the power minimization for the driver block (based on MOSFET device).

Ref. [7] describes the design of the electric circuit for the control of the piston position for a pneumatic cylinder. The hardware is built around a 32- bit microcontroller Atmel AT91SAM9G20 of ARM9™ architecture, in which is implemented a control algorithm. The position control of pneumatic cylinder is designed in the state space and is realized using a predictive controller with online identification of pneumatic system parameters; then, a reduced - order observer uses it for the state vector of the process estimation.

Another application field for the pneumatic actuators and digital control concerns the Heating, Ventilation and Air Conditioning (HVAC) equipment. Ref. [15], aiming to air-condition compressor drive system, proposes a compound control strategy based on sliding-mode observer and high frequency voltage injection method. The study is focused on improving the overall performance for all speed regions. A study focused on how the stepper motor controls the EEV for the air conditioning system is made in [14], the tests and results concerning the very popular device PIC16F877A™. Some works related to the air pressure for HVAC equipment concern both sensor unit and original algorithm / control strategies. In this meaning, [11] developed an approach for whole-house gross movement and room transition detection through sensing at only one point in the home. Disruptions in airflow, caused by human inter-room movement, result in static pressure changes in the HVAC air handler unit. According to required air pressure, the optimum motor speed is maintained by a variable speed drive which is controlled by a microcontroller. Several control strategies are presented in [2]: On / Off control, Load /Unload control, Modulation control (that meaning the position of the inlet air valve of compressor is modulated from full open to full close, Variable speed control and Blow-off control. An application for the design and development of air conditioner control card is developed in [12], and the connected circuits to the processors, like drivers, LCD units and sensors, could be standard parts of any other similar project. The main system parameters followed are temperature values for heating and cooling process and speeds for compressor motor and fan.

Beyond research studies, many modern industrial types of equipment, integrating microelectronics or digital control, are now available. Ref. [20] presents such industrial equipment – a high pressure electro-pneumatic regulator providing step-less control of air pressure proportional to an electrical signal with an easy to read digital pressure display and low power consumption. New easy-to-use high-function digital pressure sensor PPX series [23], has dual display to check current value and set value of pressure at the same time, 3-color display, copy function of setting details and 3-mode setting etc. A distinctive application field for the control of pneumatic systems concerns the buildings having a large pneumatic infrastructure [25]. A large number of such buildings are falling behind in energy management as digital systems and networks become more common and critical. New solutions come to improve the situation by converting a building with working but outdated pneumatic control system to a DDC, using wireless technology. Wireless pneumatic DDC provides rapid payback and minimal disruption to gain ongoing energy and maintenance cost savings, while improving comfort and operations. Such high performance equipment has new sensor classes, able to transmit a large amount of data by RF [22].

The paper follows a previous one [8] and the author's intentions are 2 categories: the design and manufacture of a flexible experimental platform for the air pressure control by microcontroller – this is a local goal; and the implementation of various non-conventional control algorithms (like fuzzy control), for future works, when the platform will prove all necessary capabilities. In this meaning, an inspiration source is [24], a training manual that puts together systemic / theoretical and practical elements associated with an experimental platform. Also, [3] concerns the design of such an experimental platform, where a similar pressure sensor is used. The software design support is totally different. A good source for many examples (including in the pneumatic area) is [4], where is available a project for controlling a pump from a PIC16F877™ processor via an interface made with a D/A converter followed by an integrated power amplifier.

II. Hardware Design

The architecture of the system is presented in Fig.1. The microcontroller unit (MCU) is designed around the processor PIC16F877™ – Microchip Inc. The air pressure sensor is the chip MPX5700 - Integrated Silicon Pressure Sensor On-Chip Signal Conditioned [21].

The industrial controller, as parallel solution, is the equipment UDC 1700 Honeywell [16], able to monitor and control a large variety of temperature, air pressure or fluid flow processes, with options for the output control: Solid State Relay, Relay, Triac, 4-20 mA; 0-20 mA; 0-5 V; 0-10 V.

As driver block, two circuits were used: a predriver based on the chip 74HCT541and the final power driver for the compressor, build around the MOSFET transistor IRFP150N [19], with galvanic isolation with optocoupler. Other solutions (for a variety of applications) are presented in [9].

The Control board includes, mainly: a.) reference potentiometer for the air pressure in the enclosure; b.) a program RUN switch; c.) selection switch between MCU control and Industrial controller; d.) a double jumper's selector for the characteristics choice, as in Fig. 2. The B

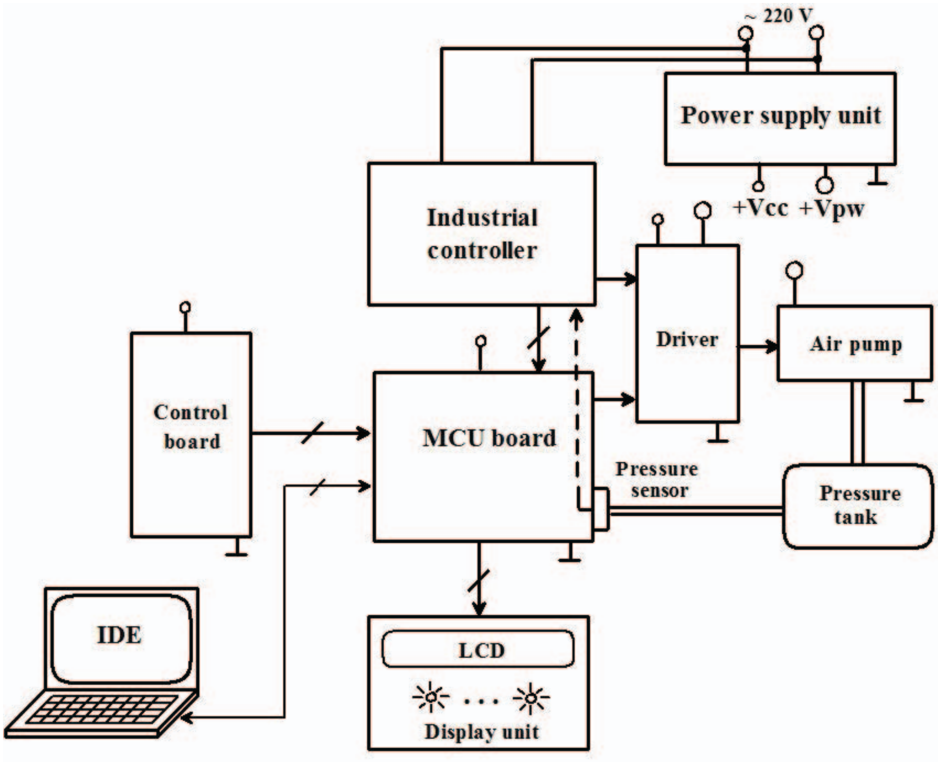

Fig. 1. The simplified structure of the experimental platform.

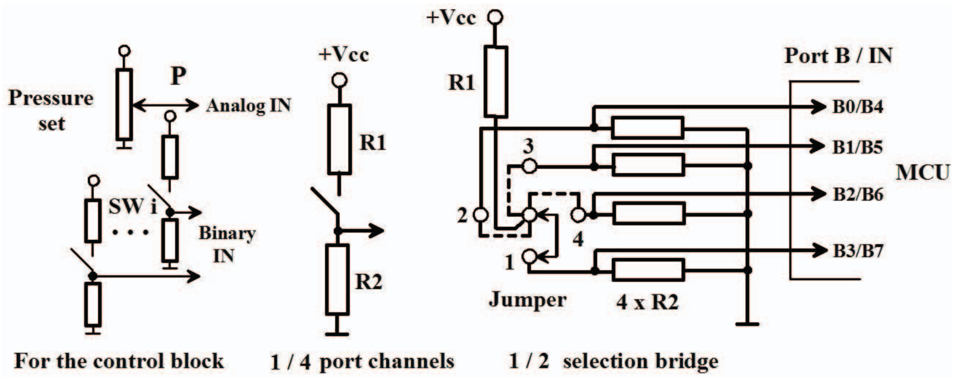

Fig. 2 The circuit for the characteristics selection.

port of the MCU is allocated to the selection function. Each 4 bits set of the port, together with the external circuit, make a 1 to 4 DMUX. B0-B3 bits select the Error thresholds and B4-B7 select the Control thresholds, together defining a characteristic.

The displaying unit has: a.) LEDs circuit for states and real-time tasks; b.) LCD board from Eblocks™ family [17], for displaying alphanumerical data.

The power supply unit has 2 sections: a.) 5 VDC for the controller; b.) 12 V DC for the air pump.

Fig. 3 contains a set of operational characteristics. Each characteristic IN – OUT of the controller is defined by the commutation thresholds: *Thres ex* is for the error of the loop and *Thresh y* is for the PWM control. For *Ne* threshold values of the error and *Nc* threshold values of the PWM control, the resulting number of the available characteristics is *Ne x Nc* (4 x 4 = 16 in Fig. 3). The characteristic no. 1 has a lower dynamic, with small control values in the region of medium and small error values. The system could behave too slowly to the steady-state regime. The characteristic no. 16 delivers the highest energy but could lead to some overshoot effects. Several experiments must appreciate each control characteristic upon the steady state error, overshoot values, time response and other qualitative and quantitative index.

For the i^th control characteristic, considering both error and control values saturated on 8 bits (0…255), the PWM

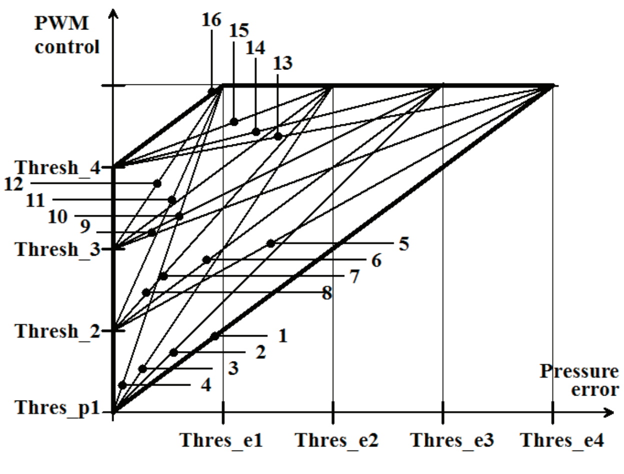

Fig. 3. A set for the control characteristics.

control is computed by program with the relation:

$$PWMcontrol = Thres\_p + \frac{255 - Thres\_p}{Thres\_e} \cdot Error \quad (1)$$

with saturation (255) for errors bigger than *255* .

III. SOFTWARE DESIGN

The main unit of the program is depicted in Fig. 4, in the Flowcode [18] style. This software has the ability to be accessible for beginners but allowing also very complex

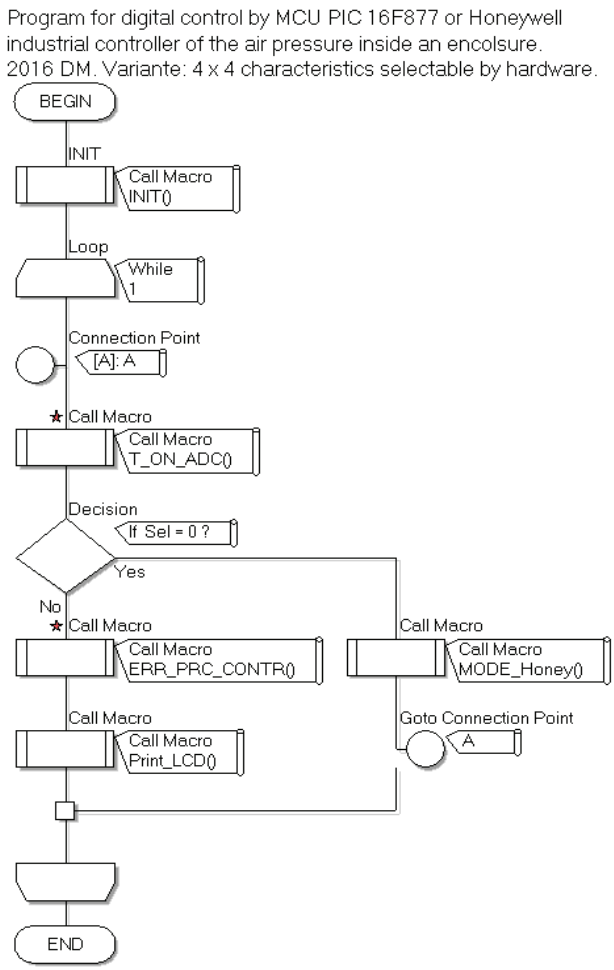

Fig. 4. The image of the Main unit in Flowcode.

programs with many units (macros), interrupts and a rich ready to use library. The author realized many complex applications in motion and temperature control fields, proving that besides CAD facilities (GUI, simulation, debugging), this environment is able to ensure high performance of results [10].

The T_ON_ADC Macro asks the state of the RUN switch (sending appropriate messages to LCD), makes the A/D conversion and read the Mode switch (MCU or Honeywell). Two parallel branches make the essential processing for MCU and, respectively, Honeywell modes.

For the characteristic selection, Table 1 has the binary input images B0_7 and the values involved in the program for a certain set for the threshold values. The procedure for the characteristic identification was conceived in accordance with the multi-decision-switch available in Flowcode, since ver. 4. D val. is the decimal value read from the port B. The quotient Q and the remainder r from modulus division by 8 are:

$$Q = [(Dval. - 1)/8]; \quad r = Dval. - 8 \cdot Q \qquad (2)$$

In Fig. 5, Q became v and r remains the same in the program notations. For each 1/16 branches / characteristics, a same generic formula is customized for the threshold values declared in the INIT block. In rel. (1), the program must use an adapted computation formula, accordingly to the arithmetic of the microcontroller CPU

Fig. 6 gives a capture of the program in simulation mode, when the MCU program Mode is selected. The graphical interface allows the viewing of all port bits allocation:

a.) 3 analog channels for pressure (reference and sensor: A0, A1) and the control output A4, scale [0…5] Vcc, delivered by the industrial controller and processed also by the MCU;

b.) 10 binary inputs: Control bits (switches) A2 and A3 for RUN program and for the Mode selection (MCU / Honeywell); Selection bits (switches) B0-7 for the jumpers that make the operating characteristic choice);

c.) PWM output – C2;

d.) 12 binary outputs: - 6 LCD control bits D0…D5; 6 LEDs bits for the real-time recording of the tasks: C0, 3, 4, 5, 6, 7.

In Fig. 6, for a pressure error of 576 mBar, on the characteristic no. 7, the output PWM control is 46 %, for a 1200 Hz fixed frequency of the pulses sent to the air pump.

TABLE I. DATA FOR SELECTING AN OPERATIONAL CHARACTERISTIC

Q	r	D val.	Bit 7	B 6	B 5	B 4	B 3	B 2	B 1	Bit 0	Thresh error	Thresh pwm	Char. No.
			0	0	0	0	0	0	0	0	-	-	"No sel."
2	1	17	0	0	0	1	0	0	0	1	255	0	1
2	2	18	0	0	0	1	0	0	1	0	192	0	2
2	4	20	0	0	0	1	0	1	0	0	128	0	3
2	8	24	0	0	0	1	1	0	0	0	64	0	4
4	1	33	0	0	1	0	0	0	0	1	255	64	5
4	2	34	0	0	1	0	0	0	1	0	192	64	6
4	4	36	0	0	1	0	0	1	0	0	128	64	7
4	8	40	0	0	1	0	1	0	0	0	64	64	8
8	1	65	0	1	0	0	0	0	0	1	255	128	9
8	2	66	0	1	0	0	0	0	1	0	192	128	10
8	4	68	0	1	0	0	0	1	0	0	128	128	11
8	8	72	0	1	0	0	1	0	0	0	64	128	12
16	1	129	1	0	0	0	0	0	0	1	255	255	13
16	2	130	1	0	0	0	0	0	1	0	192	255	14
16	4	132	1	0	0	0	0	1	0	0	128	255	15
16	8	136	1	0	0	0	1	0	0	0	64	255	16

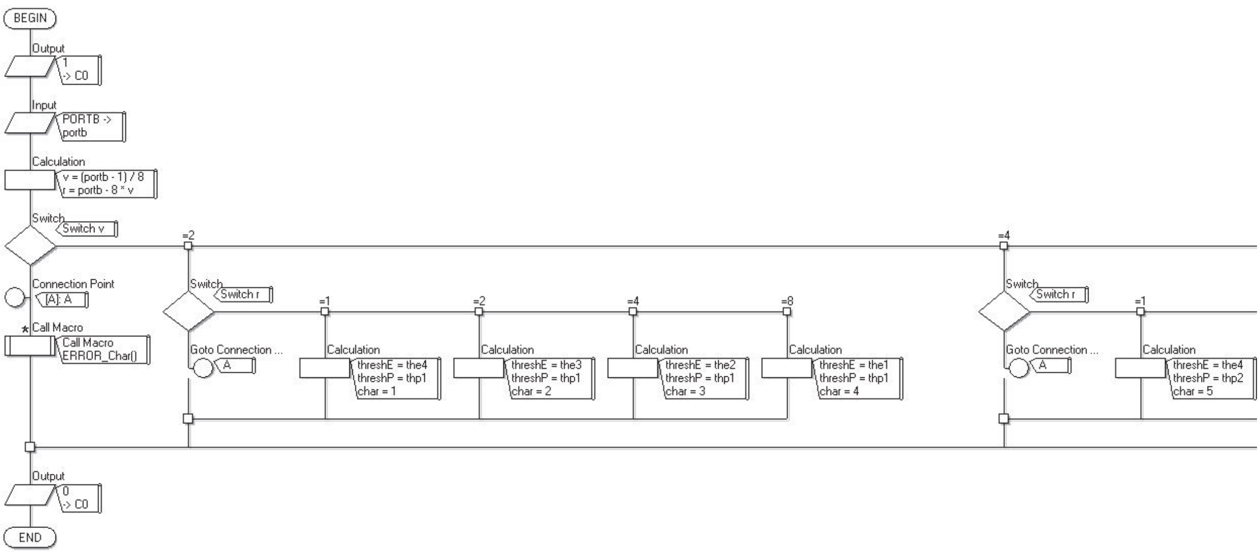

Fig. 5. The Flowcode section for identifying and computing the operating characteristic.

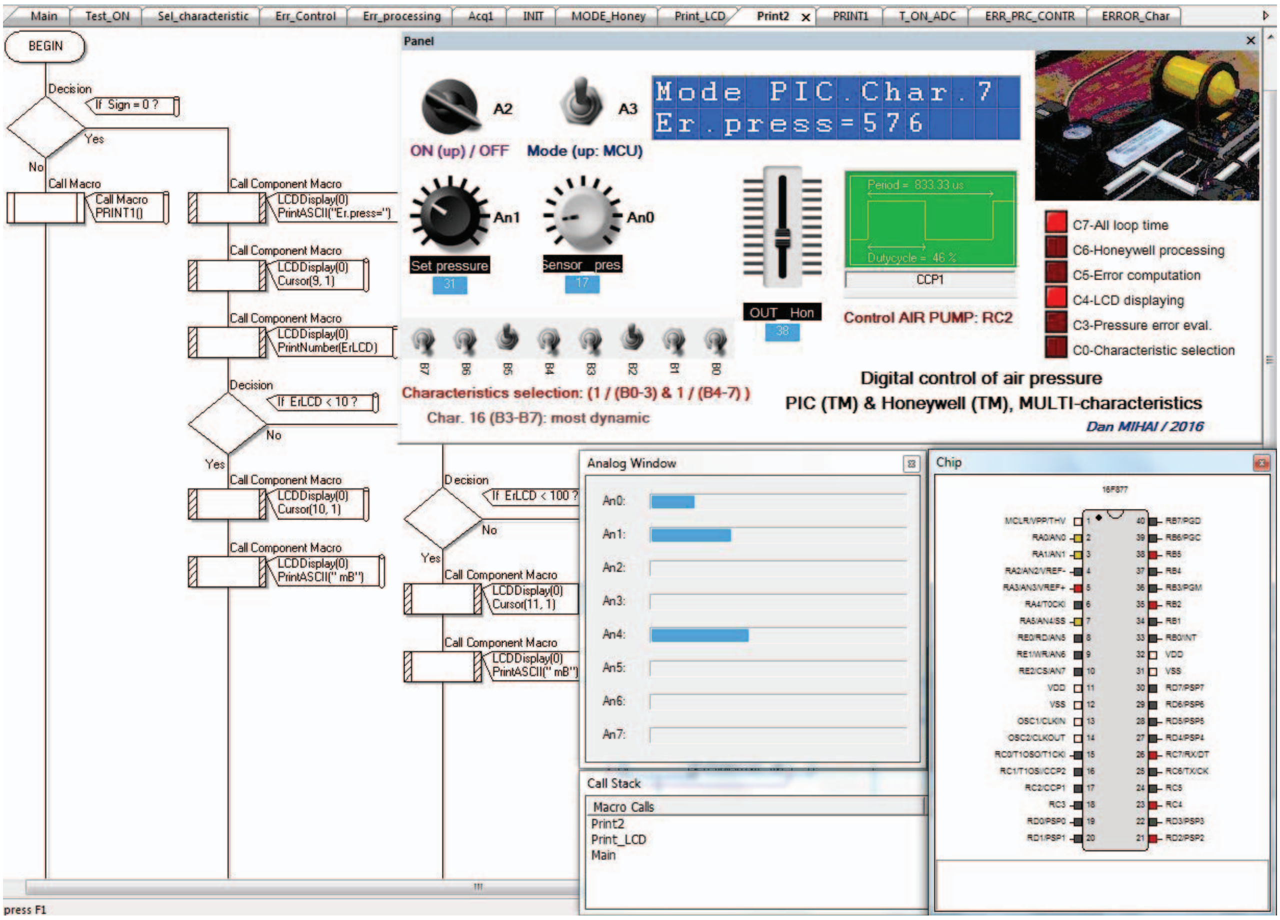

Fig. 6. The program in simulation mode.

IV. EXPERIMENTAL RESULTS

An image of the experimental platform is presented in Fig. 7, where the industrial controller is placed on the left side, in front. The air pump (left) and the pressure vessel (right) are visible in the back. The power supply unit and two microcontroller units complete the platform. A second MCU board (having its own pressure sensor) with ZIF socket for the processsor, was used in some preliminary tests for finding a suitable microcontroller. The local LCD in operation is presented in Fig. 8. The *Mode* (PIC or Honewell) is indicating which equipment is working. The selected characteristc is displayed and also the value of the air pressure error.

Next images from fig. 9 are captured by an USB logic analyzer and are useful for on-line timing evaluations. The first window has only the essential tasks: *SELECT* - selection of the characteristic: < 15 µs; ERROR_EV.: error processing and the control computation: 120 µs; *LCD*: displaying task – the longest: 30 ms; *ERR_COMP*:

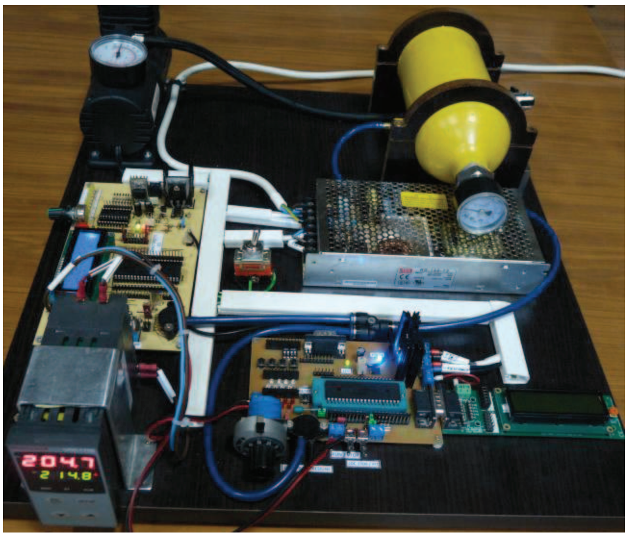

Fig. 7. The experimental platform.

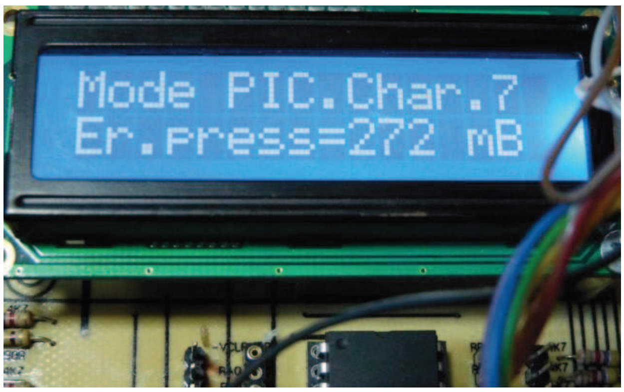

Fig. 8. The local display in operation.

routine for scaling and saturating the error for displaying it in technical units (millibar): less than 5 µs. These main operational tasks take together 147.4 µs. The second window contains the entire loop timing, with a duration of 31.46 ms. It is possible to reduce the time amount for displaying by calling this task only once for several program loops.

The on-line recordings from Fig. 10 are related with different operating points, with different speed for the air pump motor. By these diagrams is possible to follow the right and continuous variation of the PWM factor inside the whole range and to make, also, several quantitative evaluations both for the algorithm and the hardware. The captured signals concern the characteristic no. 11. In rel. (1), for this program branch, Thresh_p11 = 128 and Thresh_e11 = 128. The control formula becomes:

$$PWMcontrol\_11 = 128 + 127/128 \cdot Error \qquad (3)$$

The values for the pressure error must be arranged into the arithmetic format of the microcontroller. The range for the air pressure is 4 atm., so the LCD format is 4000 units (millibars – the most appropriate unit both for the arithmetic reasons and for the relation with the technical meaning) that corresponds to 255 for 8 bits representation.

Next computations give the theoretical values T for the sampled values and for those outputted in real-time R.

Theoretical value for the control at 100 mBar error:

$$PWMcontrol\,11_{100T} = 128 + \frac{127}{128} \cdot \frac{100}{4000/255} = 134$$

$$PWMcontrol\,11_{100T}\,\% = \frac{134}{255} \cdot 100 = 52.54\ \%$$

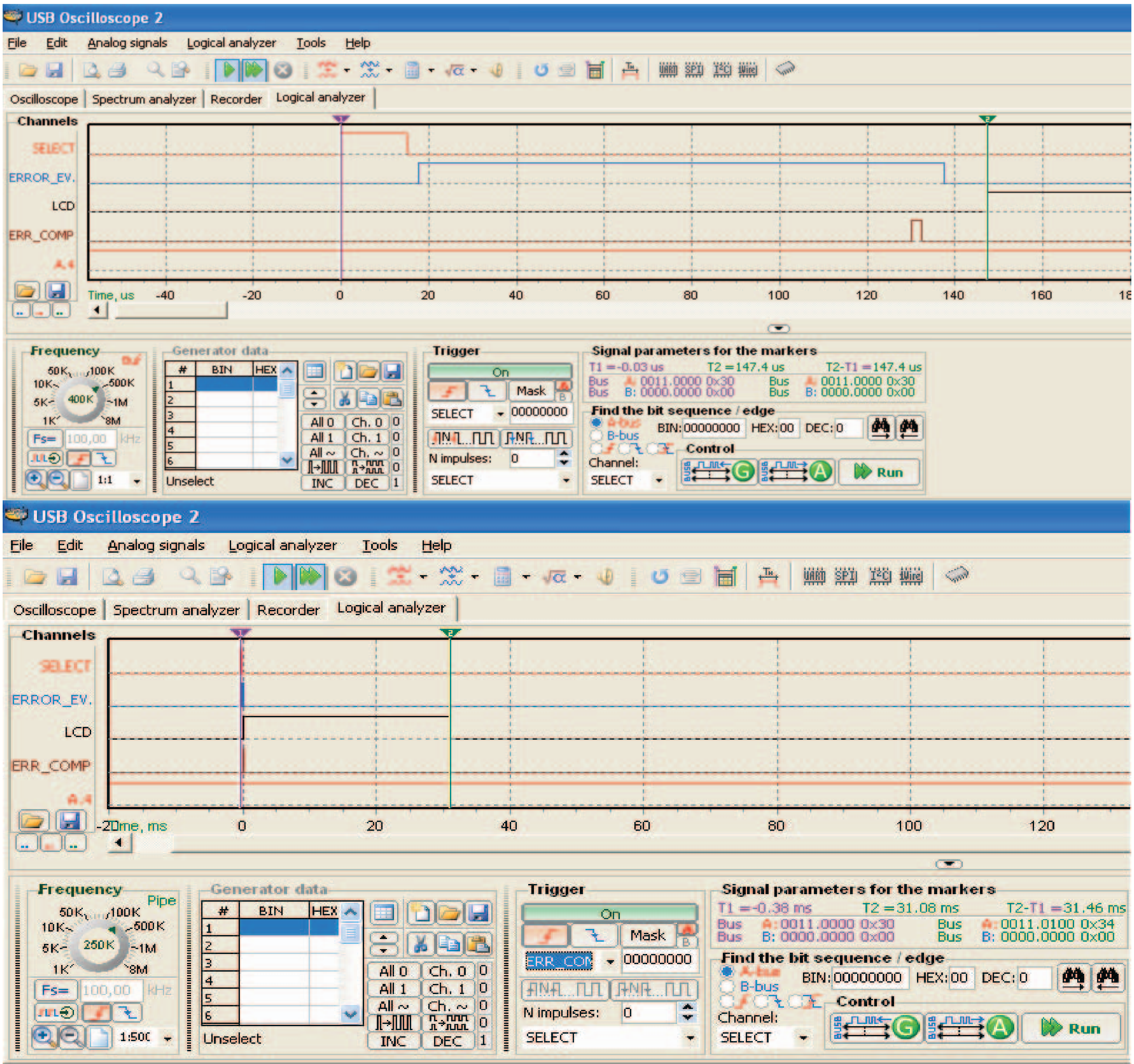

Fig. 9. Recordings for the real-time tasks.

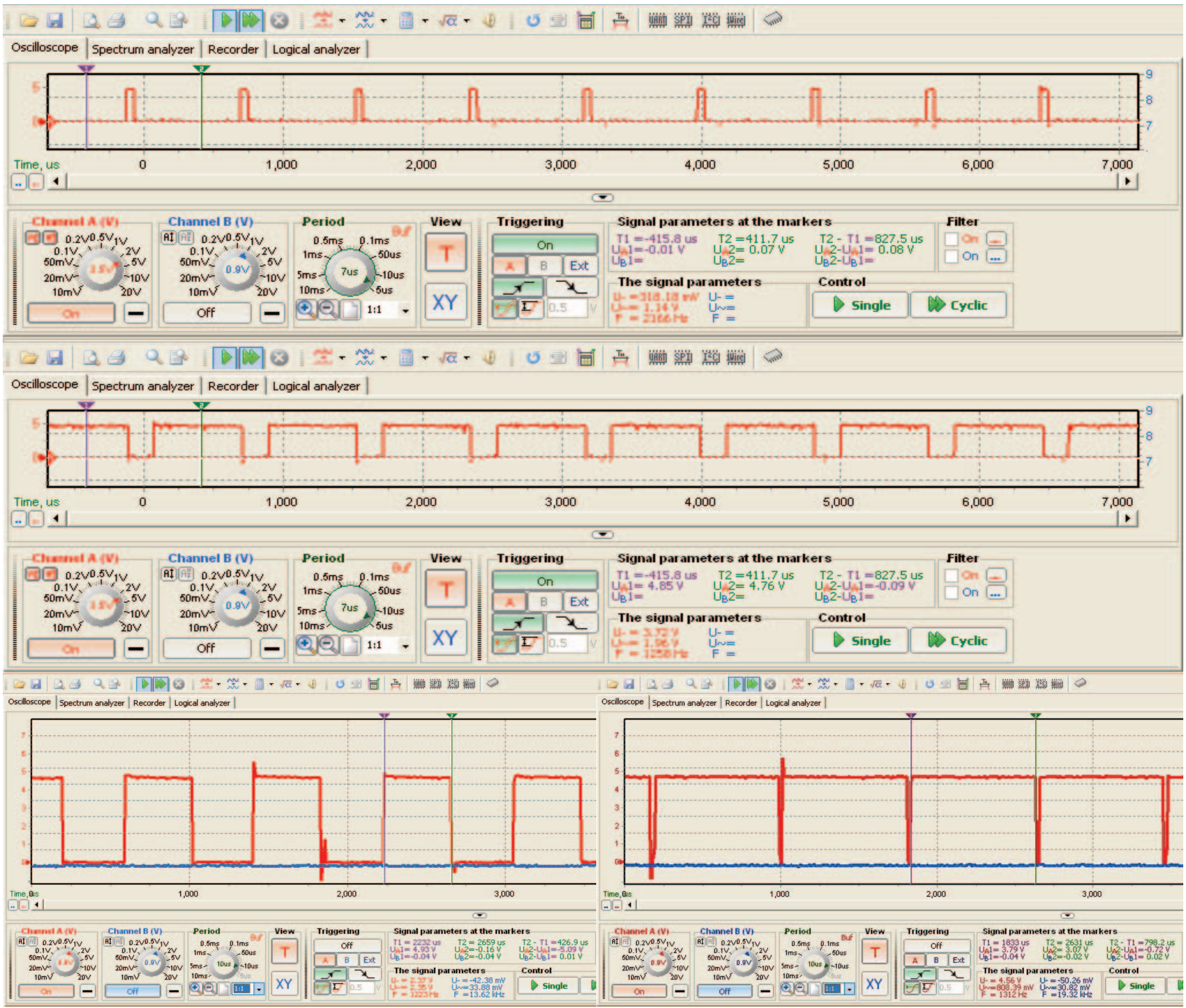

Fig. 10. PWM signals for different operating points.

The real value for the control at 100 mBar error (see T2-T1 in the third diagram):

$$PWMcontrol11_{100R}\,\% = \frac{426.9}{821.4}\cdot 100 = 51.97\ \%$$

The relative difference between $PWMcontrol_{100R}$ and $PWMcontrol_{100T}$ is 1.09 %. A similar verification computation error for the operation point with an air pressure error of 2000 mBar, leads to:

$PWMcontrol_{2000R} = 97.17\ \%$; $PWMcontrol_{2000T} = 98.83\ \%$

The relative difference for this case is 1.67 %.

V. Conclusions

The paper had several goals. The seminal start idea is to offer to the control algorithm the ability to change in real-time the control characteristic so that the dynamic of the pneumatic system could be optimized accordingly to different criterions. The hardware / software design tools are related, aiming to ensure a fast cycle by using an IDE including a VHLL for programming a modular platform. This approach is not only very efficient but also is able to offer realistic provisional results in simulation and debugging modes.

A standard industrial controller was included into the project so that a parallel operation could be possible. More, the software and the hardware design links these two solutions, the designed microcontroller based system processing some signals delivered by the industrial controller.

Several timing diagrams recorded on-line by an USB logic analyzer made possible a qualitative study (the real-time task distribution, mainly) and quantitative determinations, like the precise measurements of the durations and some evaluations of the errors between the computed (theoretical) values and the real ones obtained by experiment. These errors are very small (maximum 1.7 %) and are related, mainly, with deterministic sources: a quite short format conversion (8 bits) of A/D converter, a sampling rate not very high (tenths of microseconds) of the PCscope, chosen so that a right view of several signals be relevant (PWM frequency imposed by the air pump is not very high).

The paper did not include a study for the quality and behavior of the pressure loop (all that depending on future intended control algorithms) but to prove the functionality of the experimental platform both on hardware operation and the software tools managing the system.

The resulted experimental platform proved a full functionality and has many educational merits, bringing together many devices, circuits and equipment and involving modern software tools both for design and for acquisition.

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