DIGITAL EQUIPMENT FOR THE TEMPERATURE CONTROL INSIDE AN ENCLOSURE. THE HARDWARE AND SOME EXPERIMENTAL RESULTS

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Abstract – **The paper deals with an experimental hardware platform designed to implement and test different control algorithms for the temperature inside a thermal enclosure. The equipment was designed in a modular way and its main part is a CISC microcontroller. The results from a previous modeling study give some useful data and relations for the real-time implementation. In order to exploit all the software and hardware features of the control processor and to have a fast execution of the program, the authors preferred the assembly programming. The main hardware design elements are presented: the processor board, the acquisition unit, the drivers, the power supply block and the displaying part. The experimental platform includes the digital controller (equipment), a logic analyzer with a dedicated supplementary pod and two computers. In this extended form, the system is prepared for a complex debugging and represents a powerful education tool too. The program allows the implementation of any kind of control algorithm. The experimental results prove the functionality of the platform. The quality of these results is supported also by the on-line recordings both for the characteristic variables of the system and for the real-time tasks. These last diagrams confirm a good on-line timing and allow precise quantitative evaluations.**

Keywords: *temperature control, control algorithms, microcontroller, real-time timing.*

1. INTRODUCTION

The preoccupations to realize different kind of high quality thermal enclosures is nowadays often present in many fields. [5] makes a study on the design and construction of a small such enclosure (about 1 meter cube) suitable to perform measurements at temperature extremes. In the opposite dimensional side, in [3] is describes the development, design and fabrication of a large thermal enclosure system, which is used to perform thermal testing on a variety of spacecraft systems and subsystems. The application area is much larger. [7] deals with the temperature control inside a building where the multilevel structure, the distributed network and the random perturbations makes quite difficult the control tasks. [6] concerns the temperature control for the crops drying. In [8] is described an application of the temperature control for a coke oven in metallurgy.

After the power part is well established or build, the next main aspect concerns the control algorithm to be implemented. [9] gives an interpretation for the intelligent control, not necessarily associated with artificial intelligence but focused on robust control, advanced control algorithms integrated into a hierarchical pyramidal and distributed structure. Many researches are oriented to the use of intelligent algorithms like fuzzy and genetic algorithms. [4] makes an analyze of the possibilities for an intelligent control of the temperature inside a building with the integration of a fuzzy control into a multilevel control / monitoring structure.

A subsequent and useful gain of the work is the pedagogical tool obtained having a versatile system for controlling the temperature. It brings a strong and convincing support in teaching embedded systems, for the design and optimization of the control algorithm of any kind. Even in an era where the virtual teaching and experiment become very popular, the integration of physical experiment remains a valuable option – [1], [10], [11] and [12]. For the training of the students in electrical engineering, the temperature control will be always a valuable support in the understanding, designing and experiencing both hardware and software knowledge and tools.

The main objective of the work is related to the necessity for having an experimental platform for the study of different classic or unconventional control algorithm for temperature inside an enclosure. A first design stage was presented in [2] and a hardware / experimental stage is described here.

2. THE HARDWARE

The hardware design is in connection with the systemic and software preparation – [2] and implies the next steps:
- the choice of a control processor. The authors preferred the very popular (and successful) 80C552 microcontroller unit (MCU);

- the configuration and the design of the equipment – fig. 1, with a main processor board, data acquisition boards, peripheral boards, power supply units;
- the design of the appropriate drivers;
- the identification of all physical connections between modules / circuits, accordingly to the MCU ports and to the existing or new designed interfacing / processing boards;
- the transfer of the program into the MCU NVRAM memory;

The main parts of the platform are:
- the digital equipment, including:
  - the MCU board, with the all related devices (clock circuits, EPROM, NVRAM, RS232 …);
  - the power supply units;
  - the analog unit (conditioning block for the input signals, drivers, digital-to-analog module);
  - displaying unit;
  - operator controls and the associated circuits.
- the thermal enclosure – [2];
- an interface with the logic analyzer;
- a logic analyzer;
- a computer for developing the software application and for on-line data acquisitions;
- a computer connected to the logic analyzer.

The equipment has the next main functions – fig. 1:
- the control of the temperature inside the enclosure according to a digital control algorithm (any kind);
- the displaying of the reference and of the real temperatures, as well as of some important states of the system.

The driver has 2 sections, for a PWM control and for a continuous (analog) mode. The application program is hosted by a NVRAM memory. The power circuit and the essential units are shown also by fig. 2. The sensor is an LM235 IC and the connection with the controller is made by a shielded cable. The signal is amplified so that its range is calibrated to the ADC input of the MCU. A similar analog circuit processes the reference signal from a multi-turn potentiometer. The output signals of the controller are driven (via an 8 bits DAC and operational amplifiers) to a power transistor for the analog mode and to a power IC (L298 – ST Microelectronics) – for the PWM mode. The selection between these modes is made manually. The pictures from fig. 3 present some relevant images of the hardware, from the controller board to the entire platform. The power supply unit has an AC/DC 5 V/10W unit and another one AC/DC 12V/40W, plus integrated DC/DC ICs for the reference signals.
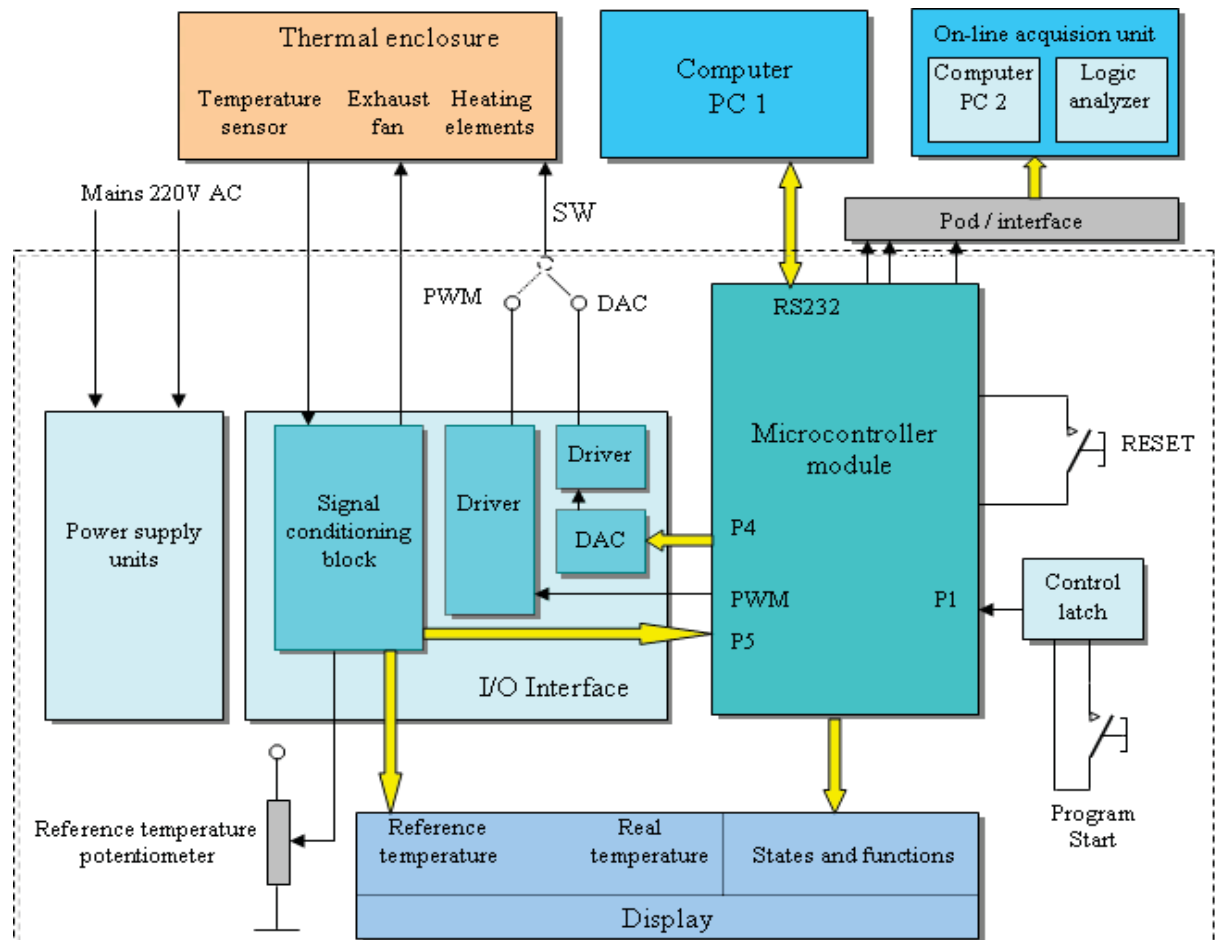

Figure 1: The experimental platform for the digital control of the temperature.
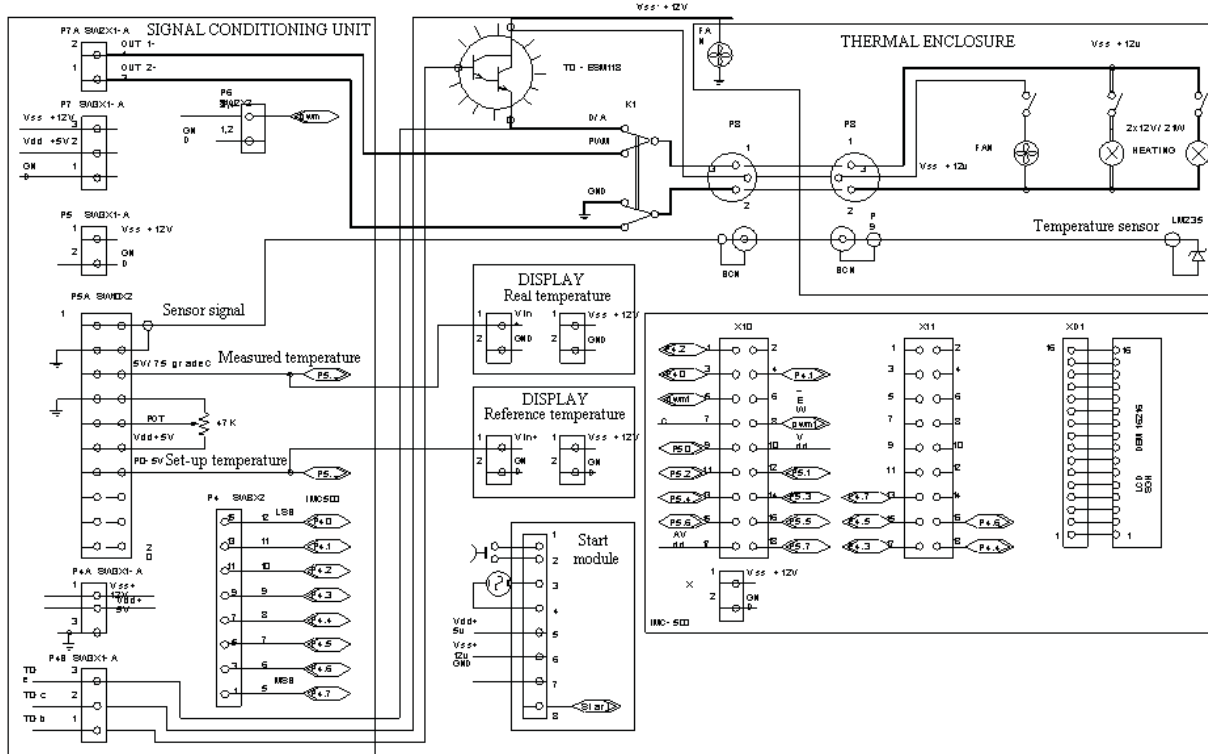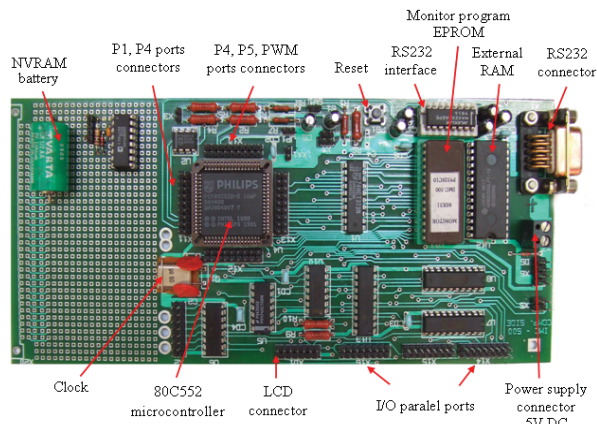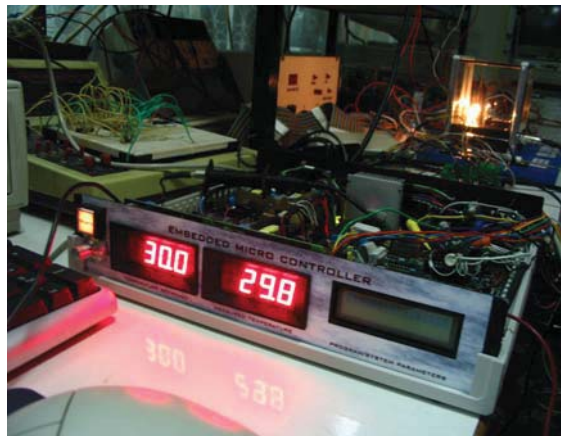
Figure 2: The main circuits of the equipment.

The main controller board.

The equipment in operation.

A top view of the equipment.

The whole platform.

Figure 3: Some images of the experimental platform.

3. THE APPLICATION SOFTWARE

For exploiting all hardware and software capabilities of the MCU as well as for a fast execution and a full control of the real-time tasks using the interrupts, the application program was written in assembly language. The modules are:
- the main program, with the next functions:
  - initializing: registers, interrupt system, data area;
  - the interruptible loop.
- the interrupt service routine (by internal timer) for:
  - the sampling period generation;
  - the analog signal acquisition / conversion;
  - the acquisition of the operator signals;
  - the computing task (with arithmetic routines);
  - the data savings and the regressors updating;
The sampling period is adjusted by programming the T2 timer, using its CM0 (compare) unit:

$$N_{CM0} = \frac{T \cdot f_{clk}}{12 \cdot k_p} \leq 2^{16} - 1 \tag{1}$$

k_p is the prescaler factor. For bigger T, the program can multiply the maximum value from (1). Next lines ilustrate a slice from the computing task:

```
        mov a, atrefl  ; temperature error
        clr c
        subb a, atl     ; CY set to neg. error
        jnc goon        ; err > 0
        mov aeks,#01h ; err < 0
        mov a, atl      ; error module
        clr c
        subb a, atrefl
        mov aekl,a
        ljmp alfa
goon:  mov aekl,a
        mov aeks,#00
alfa:      ;  Compute term PI 1 = acck1
        mov r2, aekl  ; 256 x ek, signed
        mov r1, #00h
        mov r3, aeks
        mov r0, #k12
        mov r4, #00h
        lcall impartr  ; term1- 16 bits, sign in acck1
        mov acck1l,r6
        mov acck1h,r7
        mov acck1s,r3
```

4. THE EXPERIMENTAL RESULTS

Different diagrams from fig. 4 give the image of the main variables: the reference and the real temperatures (fig. 4a, 4c), the error temperature and the control (fig. 4b). Each diagram has the necessary explanations (variable, units). The very realistic curve 4c was kept for underline some parasitic signals (from a first undersized power supply) and ripples of different nature: inside the hysteresis band (4b) and in 1 LSB limit range (4c). For having clean diagrams (the real temperature is smooth), a 2 stage filter was applied: a Savitzky-Golay one and a next standard 1st order filter. The effect of each such filter is made visible by fig. 4d and 4e. It can be seen on the control diagrams the exit from the saturated regime (4b) and the pulses modulation (4d). The low overshoot of the temperature means a good tuning of the loop. All these results confirm a right operation.

A valuable certification of a right real-time operation was obtained recording the main MCU tasks – fig. 5 and 6. The meaning of the channels notation: SPERI - the sampling period; MAINP - the main program; READC – analog-to-digital conversion for the reference signal acquisition; RTADC the same, for the real temperature inside the enclosure; COALG – the control algorithm; DSAVE – data savings in the NVRAM memory; DYSPL / LCDTK – display to the LCD; COBx: the state of each x channel of the output port (P4). The total length of the control algorithm is 248 µs (fig. 5a) for a hysteresis algorithm. It can be seen how the processor is assigned to the task inside the interrupt loop during the MAINP and DYSPL tasks. The ADC and DSAVE tasks need almost the same time, bigger that for the control algorithm. Fig. 5b captured a simultaneous change of the state for all the port and the long recording time from the fig. 5c contains an entire regime.

The time length for a digital PI algorithm (384 µs - fig. 6a) is higher by more than 50 % from the hysteresis variant and now each channel of the port can commutate independently – fig. 6b. The first recordings were made for T=100 ms but the last one uses T=2 s. Such recordings are useful both for having a real confirmation of the right timing as designed by the program and for a precise quantitative evaluation of the time intervals.

4. CONCLUSIONS

The paper, as continuation of a previous work, presents a digital equipment integrated into an extended experimental platform for the control of the temperature inside a thermal enclosure. The same equipment makes the control of the loop as well as the storage of the main systemic variables. Their diagrams confirm the functionality and the quality of the equipment. Other results inserted into the paper are the on-line commutations associated to the real-time tasks, captured by a logic analyzer. Such kind of timing diagrams confirm too a right operating of the designed hardware and software. The successful design was possible by a previous modeling / simulation study. The platform allows the implementation and the test / tuning of any kind of control algorithms (conventional or not). The same equipment provides obvious benefits as educational tool.
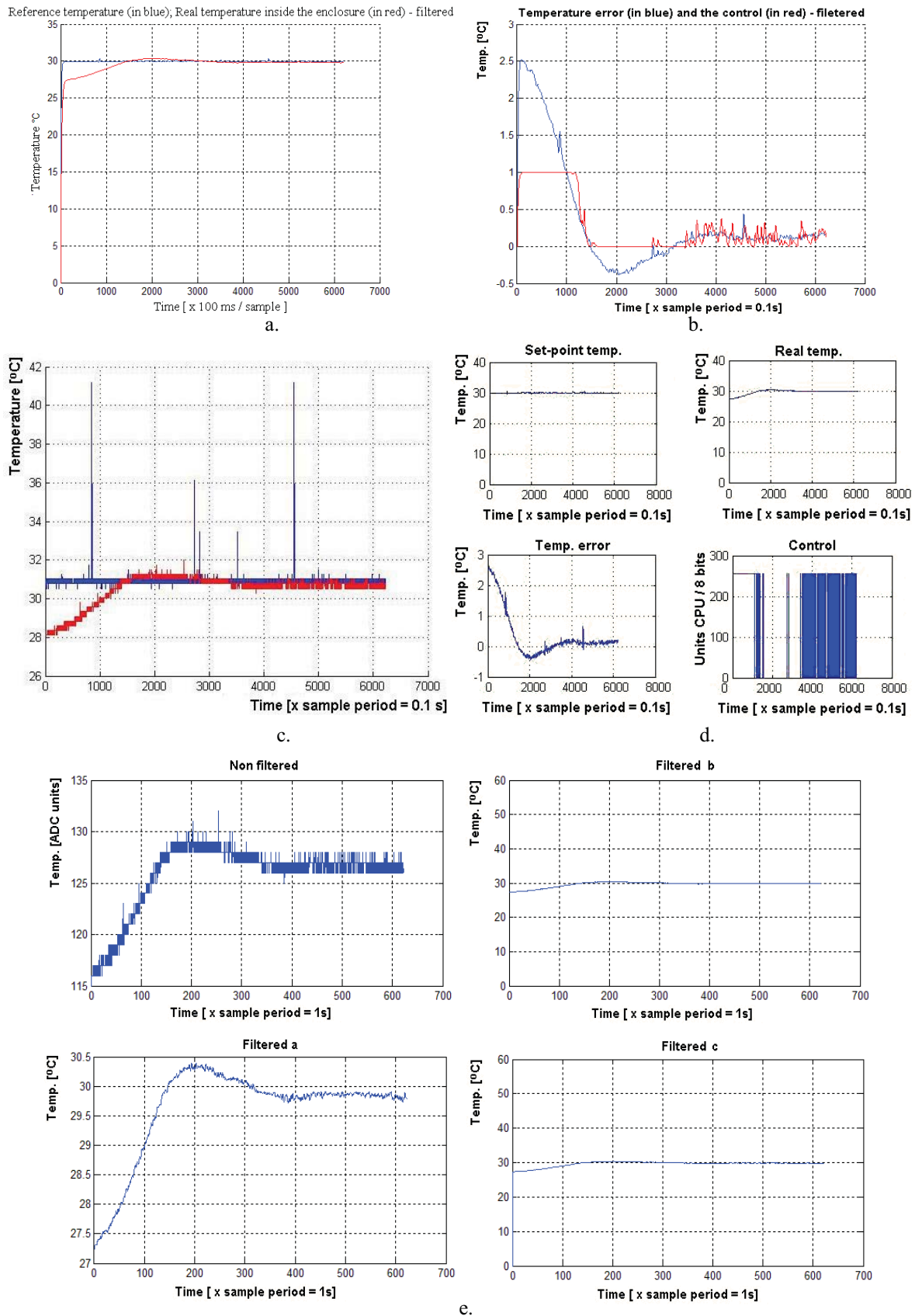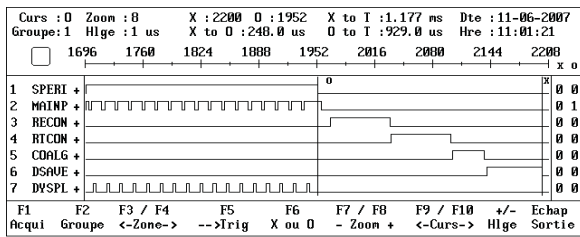
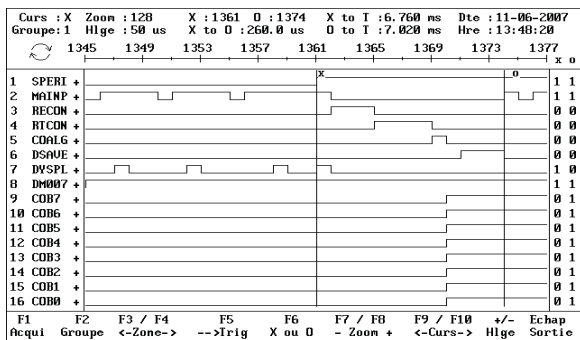Figure 4: The evolution of the main variables in real-time.

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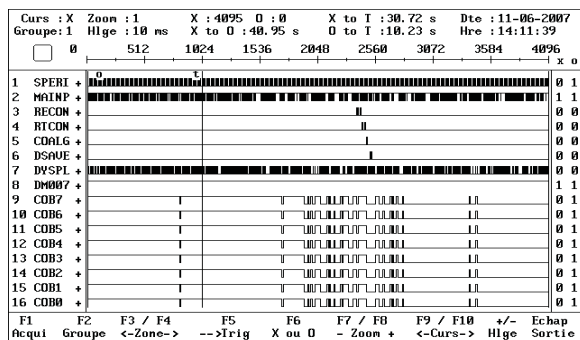
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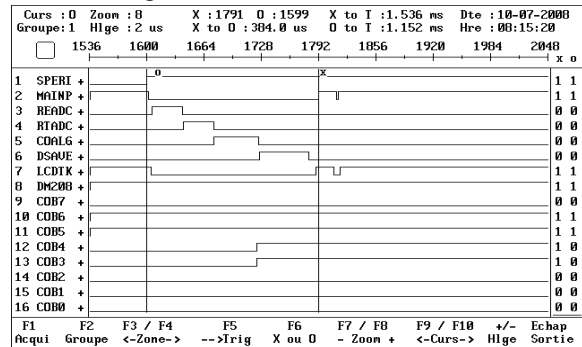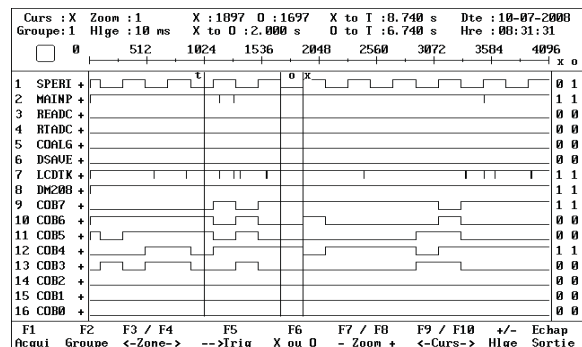
Figure 5: Some on-line recordings of the real-time tasks for a hysteresis control algorithm.

Figure 6: On-line recordings of the real-time tasks for a digital PI control algorithm.