# VirtuaLab, a Teaching/Learning System for 8 and 32 bits Microcontrollers

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*Abstract*— **This paper describes the current state of the VirtuaLab facility at the Universidad Carlos III de Madrid. Under an authenticated access, the system allows to control a microcontroller based modular system, with visual feedback to the remote user through a web camera. VirtuaLab allows control through Internet of the same laboratory resources used on–site sessions from inside and from outside the campus area.**

***Keywords-virtualab; e-learning; microcontroller; ARM7; 8051***

## I. INTRODUCTION

Microprocessor learning sometimes becomes a hard assimilation effort to students, requiring in addition a lot of attention to details in order to accomplish the mandatory practical laboratory sessions, [1].

Furthermore the necessarily limited time assigned to each session can be not enough, by the own difficulty of the exercise or because the student has the will to get a better insight of the full system working.

Although the market offers low cost evaluation microcontroller boards, buying one kit is not a common approach for a typical student, so the possibility to access a remote laboratory adds a useful complement to the traditional sessions into a laboratory with fixed training schedule.

This paper presents a modular system which can be used both into on–site sessions, and also from Internet using a software application which gets the total control of the PC based development platform, located into the real laboratory.

The developed platform is flexible enough to integrate available commercial evaluation boards, so avoiding microcontroller obsolescence and easing the migration to new models with low effort, [2, 3]. In this way, we use a project based learning approach, in the same path that other authors have followed before, [4, 5, 6].

Organization of the paper is as follows: section II explains the HW resources of the platform, while section III details the SW solution adopted in order to manage the access to system and to administrate the users Data Base; section IV describes some of the laboratory assignments to students. Finally, section V presents the evaluation results, and section VI summarizes the main conclusions reached during the life of the project.

## II. HARDWARE DEVELOPMENT PLATFORM

### A. *Microcontroller board of 8 or 32 bits*

The system can use any microcontroller of 8, 16 or 32 bit, usually included onto a commercial evaluation board, which makes the full system close to a real application. The actual system built use two completely different chips:

An 8-bit system, actually the evaluation kit C8051F226DK from Silicon Laboratories, a model derived from the original Intel 8x51 design.

A 32-bit system, the Keil MCB2100 kit that includes an evaluation board for the NXP-Philips LPC2148, based on an ARM7 CPU, a more complex and powerful model [2].

We have designed the board E/S MICROS in order to have control of different peripherals. The different interfaces use a specific I/O pins assignment and routing board for each one of the microcontrollers and, of course, requires its own software routines.

This special pin adapter board allows the connection of the concrete evaluation board used with the E/S MICROS one, using flat cable. The last one includes several input/output peripherals, which the user can freely combine.

Usually students program its assignment works on C and Assembler languages.

Actually, we are using IDE from Silicon Labs and µVision3 from Keil/ARM as development environments, which include tools that let to edit, assemble, compile and link programs, and then run and debug it when they are errors' free.

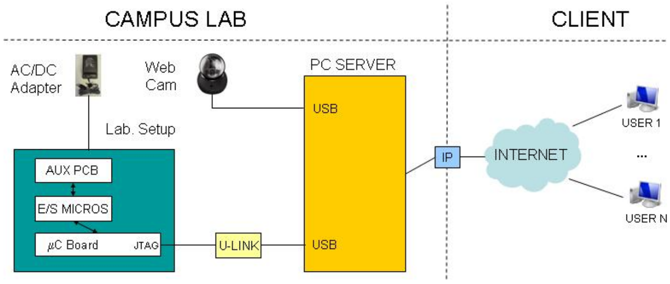
### B. *E/S MICROS peripheral board*

This board includes a keyboard/keypad, an LCD liquid crystal display, a LED's matrix, an RS-232 serial port, an $I^2C$ EEPROM and $I^2C$ potentiometer, an infrared receiver, and a triac for AC phase control.

An expansion board adds to this E/S MICROS some peripherals, better placed outside of it because of space constraints: these are a little speaker, a power relay, a DC motor and a photo detector of the motor axis spin.

Keyboard: is has a 4x4 cross-matrix organization.

Figure 1. Schematic diagram of the complete system




LCD liquid crystal display: the character display module has two lines of 16 symbols. The HW interface is common to several models, making feasible to mount another one with a different number of lines or character, e.g. 4x20.

LED's matrix: this display has a 7x5 dots format to show the desired configuration. To reduce the number of pins, the microcontroller connect through the serial input of two 74HC595 shift registers, and its parallel outputs connected to ULN2003A drivers.

RS-232 serial port: this module includes a MAX233 level converter and a standard DE-9 connector.

$I^2C$ devices: the board includes two devices with this type of interface: an EEPROM memory and a digital potentiometer. The 24LC16 memory has 16 Kbits but a higher capacity model can replace it. The DS1803 digital potentiometer, with 256 different output levels, controls the DC motor through an amplifier, and can connect to other devices.

IR receiver: With this device, it is possible to implement an infrared remote control that offers complete user isolation from AC powered devices, and allows controlling onboard peripherals through a remote wireless channel. It uses the Sharp IS1U60, an infrared receiver with a lens included.

AC phase controller: With this module, it is possible to manage up to 1 KW, through the triac phase control of an AC line. To get a safe operation, opto–isolators completely separate the power and control sections.

Speaker: a microcontroller output reaches an audio amplifier and this to a little speaker. A manual amplifier gain control, allows adjusting the volume of sound. By creating a memory table of frequencies associated to each musical note, it is possible to associate a different tone to each key or even play previously stored melodies.

Figure 2. View of E/S MICROS peripheral board

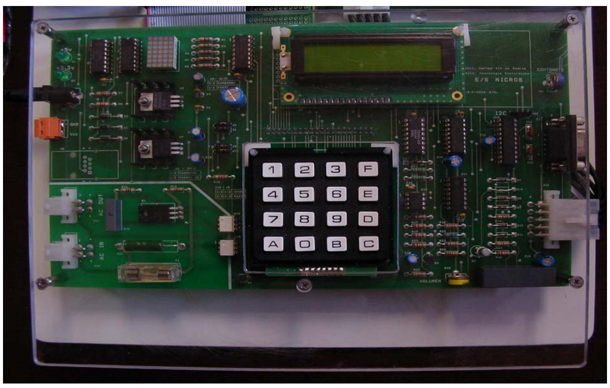


Figure 3. Platforms for ARM7 and 8051 VirtuaLab

Relay: it can switch on or off, signals of relatively high power, with galvanic isolation from control electronic.

DC motor: this type of motor finds typical application on micro-robots, toys etc. Its can be controlled directly with a variable DC voltage or through a PWM signal, which is the preferred technique. The module includes also a motor spin detector, based on the H21A phototransistor optical switch; to this end the motor mounts an X shaped piece fixed to the axis, which cuts the light path when spinning.

### C. *Complete hardware platform*

Fig. 3 shows the two platforms, including the following components: microcontroller evaluation board, E/S MICROS board, expansion board, interconnecting cables and two supporting plastic sheets, the upper one of transparent polycarbonate.

Also included is a webcam of 640x480 pixels resolution and maximum rate of 30 fps and an auxiliary lamp. The visualization software is the AMCAP v1.00 bundled with the Trust Spyc@M100 camera model. In this application, we do not have special video bandwidth requirements, [7].

This constructive system based on independent modules, makes possible to protect effectively the HW of improper user handling. At the same time, it makes easy the substitution of modules by obsolescence, fault or upgrade, [8].

## III. SUPPORTING SOFTWARE

The management and control software of VirtuaLab has been developed under Delphi. It uses the Windows Remote Desktop to access from Internet an on–site laboratory where a PC computer runs Silicon Labs IDE or Keil µVision3. The system authenticates the user to verify its access rights, and then he can work up to a maximum allowed time of 1 hour.

To get access, the PC requires a name and password fig. 4. When the system is busy, it denies the access, as VirtuaLab attends one user at time while working in non-stop mode.

A user is blocked after some failed access attempts but after a 24 hours lapse he is automatically restored. Five minutes before the session ends, the system sends a warning message to close opened files and save code changes, fig. 5.

Figure 4. Access screen to VirtuaLab


On the PC client side, the user needs a remote desktop connection, but a high-speed link is not required. Universidad Carlos III offers to its students several rooms with access to a large number of computers connected to Internet. By using these PC or a wireless notebook connected to the local Wi–Fi, it is possible to access VirtuaLab from inside the academic campus. The students also can access the system from outside, for example from the own home through Internet.

After login, the user execute the webcam and IDE programs from the start menu of the remote laboratory PC, and begins to work as if he were into the lab, near to the development platform.

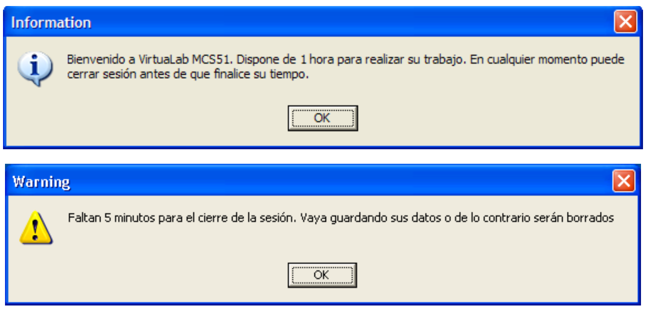
An obvious limitation of the system is that the input keypad is not physically accessible. In this case and when debugging an application, the user must use some technique equivalent to the keying action, e.g. changing a register or variable using a program breakpoint.

As a help to the instructor, it is possible to run an auto-test program, which allow verifying the integrity of any of the HW modules included in the system. This tool is useful to confirm that there is no hardware malfunction so a program module is incorrect and also to locate and repair a device fault.

The availability of a library of functions, which handle the full set of HW resources, offers the possibility of making some complex practices before the students have developed and debugged their own programs for all of the required modules.

Two library sets are available, one for each microcontroller model, in order to use, invoke and link without access to the source code. This feature has probed to be a strong advantage to learn the functionality of the full system.

Figure 5. VirtuaLab Welcome and Timeout warning screens




The Data Base includes a record of students, which can work with VirtuaLab, a timetable of its assigned slot time, and a historic register of accesses to system. If a student does not login the system within 15 minutes after the beginning of its time slot, any other user can gain access to it. This rule allows that anyone can use the system when it is idle.

Several security layers are included to avoid undue access to system. For example, to key the password the student uses a mouse over a virtual keypad onto the screen. As additional protection, we use an encrypted hard disk database, to avoid changes made by non-authorized persons.

The system administrator has its own special password to access database records, listings and control screens. In this mode, it is possible to get individual, group or global reports, selecting different fields of interest. Administrator can insert/delete users, manage blocked accounts, see access and time history, make searches by name or group, and define reports listing. Recording the number of access and consumed system time helps the evaluation of each student and group. The graphic interface has been refined along several years of use, in order to be intuitive and user friendly.

## IV. LABORATORY PROJECTS

Let us shortly describe, some of the practical exercises proposed to students of different engineering degrees:

### A. *Using 8051*

1. Speed control of a DC motor: the speed must change under keyboard command. The measured speed on rpm shows over the LCD. The program should use specific functions to develop. The user writes and debug in assembler and in a posterior session, he do it again using only C language.

2. LCD scrolling display: includes the use of keypad and LED's matrix; shows a 4-line message on a 2x16 LCD.

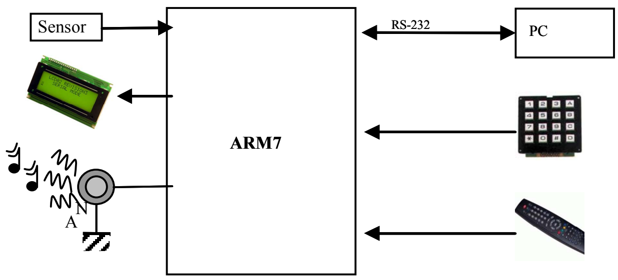
3. Serial link: communicates the microcontroller through a RS-232 interface with HyperTerminal running on the PC. LCD upper line shows data received from PC and the lower line show the data entered through keypad and sent to PC.

### B. *Using ARM7*

4. The assignment is to build a complete alarm system, following a progressive process along several sessions, [9].

The alarm system detects presence with an analog sensor input, whose value must be higher than a certain level. In this case, the system generates an audio alarm and sends a message to a PC through the serial port.

Figure 6. Domestic alarm system based on VirtuaLab



The alarm system starts by entering its PIN number and silence by a command sent through the IR remote control. The system signals its state on the LCD, adding audible feedback to entered keys. It is possible also to activate the audio alarm from the PC sending a special message.

The last sessions are usually very instructive for the students, when the working team of each group must resolve some rather unexpected integration problems.

## V. EXPERIENCE RESULTS

The Electronic Technology Department of Universidad Carlos III de Madrid UC3M, has 50 full kits for laboratory practices, including the I/O boards and the corresponding evaluation boards for microcontrollers of ARM7 and 8x51 families: Keil LPC2129/MCB2100 and Silicon Labs C8051F226.

Courses belonging to different three years engineering degrees at UC3M use this equipment kits at on–site labs. Actually, these second year courses belong to three different degrees:

- SED II, 8051 based. Degree ITI Electrónica Industrial (EI)
- SED, ARM7 based. Degree ITT Sistemas de Telecomunicación (ST)
- Microprocesadores, ARM7 based. Degree ITT Telemática (Tel)

### A. *Academic results*

The following histograms summarize the results of several years and degrees. The X-axis shows reached marks from zero to ten, and Y-axis the annual percentage of students within a mark in that course.

For SED II we have 4 years data, from 2006 to 2009.

The data on SED covers from 2007 to 2009, and we only show the histogram for the three years average.

On Microprocesadores, we have data from 2006 to 2009 while fig. 7 shows the average histogram for these 4 years.

Figure 7. Four years academic results from SED II (EI)

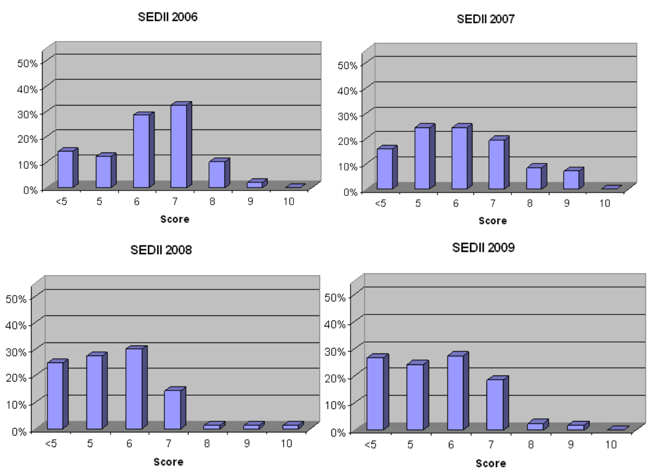
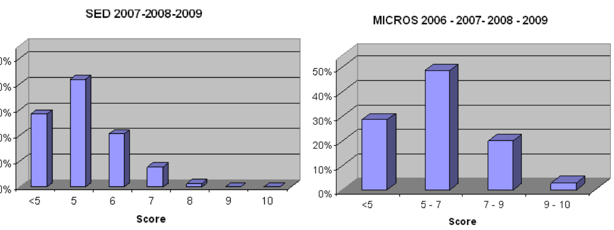



Figure 8. Academic results of SED (ST) and Microprocesadores (Tel)




### B. *Student perception of results*

We have carried some surveys on students the first two years after the introduction of the remote lab. Tables show the results for SED II on 2007, which agrees with other courses.

- General questions:

Q1: My topic interest has increased after the practices

Q2: I should like to study an advanced course on this topic

Q3: Practices are useful to understand the theory

Q4: Tell if the practices balance is right

- On–site Laboratory

Q1: Mark the usefulness of this type of practices

Q2: It promotes to work into a group

Q3: The number of exercises has been enough

- Remote Laboratory VirtuaLab

Q1: Mark the usefulness of this type of practices

Q2: It promotes an individual work

Q3: Working remotely with VirtuaLab has been easy

TABLE I. STUDENTS PERCEPTION AT SED II (EI)

| General questions | Responses | | | | | |
|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *Av.* |
| Q1 | 1 | 3 | 2 | 10 | 9 | 3,9 |
| Q2 | 2 | 2 | 9 | 9 | 8 | 3,6 |
| Q3 | 0 | 1 | 3 | 15 | 11 | 4,2 |
| Q4 | 3 | 2 | 4 | 11 | 10 | 3,8 |
| **On–site lab** | **Responses** | | | | | |
| Q1 | 1 | 3 | 4 | 15 | 7 | 3,8 |
| Q2 | 0 | 0 | 5 | 11 | 14 | 4,3 |
| Q3 | 2 | 3 | 3 | 6 | 16 | 4,0 |
| **VirtuaLab** | **Responses** | | | | | |
| | *1* | *2* | *3* | *4* | *5* | *Av.* |
| Q1 | 1 | 3 | 2 | 10 | 9 | 3,9 |
| Q2 | 2 | 2 | 9 | 9 | 8 | 3,6 |
| Q3 | 0 | 1 | 3 | 15 | 11 | 4,2 |

Marks qualifies from 1 (strongly disagree), to 5 (strongly agree)

In general, we think there is not a clear difference on the average academic results due to the introduction of the remote lab, although this is true for the more interested individuals, [10]. The student perception of VirtuaLab is good, but cannot be used to a fair comparison, because they have no experience of the same practices with and without a remote lab.

## VI. CONCLUSIONS

The major perceived effect of access to VirtuaLab laboratory is an increase of the time students spend working with the microcontroller platform, because of some well-known real practical constraints, that up to now only this approach has probed to solve.

The remote lab is a complement to the conventional one, as it cannot completely replace it, although it is still possible to apply the transfer of training concept, [11].

Other studies as [1, 12, 13], have not detected any significant difference of results between remote and on–site labs of similar contents, in agreement with VirtuaLab findings.

Therefore, this additional time devoted to put in practice the concepts explained at classroom, is likely to increase the practical development skills of students, and as a consequence a better insight of the course topic.

From the point of view of instructors and school management, there are also significant gains in terms of time and resources assigned to classroom training, as more students can progress by auto learning, without close teacher attention.

VirtuaLab offers conceptual advantages from different points of view: a flexible HW platform able to use any microcontroller based on commercial evaluation boards, changing only a passive I/O pin routing adapter, and a mechanical design able to withstand heavy use, protecting effectively the platform of improper user handling. At the same time, it is easy to substitute any module by a fault or upgrade to a new microcontroller, [8].

From the SW side, it allows students a local and remote access to develop, download code into microcontroller flash memory, debug and run a program, while records its working data for teacher's control and management.

As a dedicated system, VirtuaLab allows the control of a broad range of peripherals, has flexibility to change easily the microcontroller board avoiding obsolescence, and to control the students working time, all of these maintaining the same HW platform used in an on–site lab.

However, as the market evolution brings cheaper boards and link dongles, the use of low cost individual trainers could become a real alternative to these dedicated types of systems.

## REFERENCES


[1] J. Trevelyan, "Lessons learned from 10 years experience with remote laboratories," in Int. Conference on Engineering Education and Research, Ostrava 2004.

[2] Nooshabadi, S., Garside, J. , "Modernization of teaching in embedded systems design-an international collaborative project," IEEE Transactions on Education, vol. 49, issue 2, pp. 254 – 262, May 2006.

[3] Mossin, E.A., Passarini, L.C., Brandao, D., "Networked control systems distance learning: state of art, tendencies and a new fieldbus remote laboratory proposal," IEEE Int. Symp. on Ind. Electronics, ISIE, pp. 1870 – 1875, June 2007.

[4] Macias-Guarasa, J., Montero, J. M., San-Segundo, R., Araujo, A., Nieto-Taladriz, O., "A project-based learning approach to design electronic systems curricula,", IEEE Transactions on Education, vol. 49, issue 3, pp. 389 – 397, Aug. 2006.

[5] Ferrater-Simon, C., Molas-Balada, L., Gomis-Bellmunt, O., Lorenzo-Martinez, N., Bayo-Puxan, O., Villafafila-Robles, R., "A Remote Laboratory Platform for Electrical Drive Control Using Programmable Logic Controllers," IEEE Transactions on Education, vol. 52, issue 3, pp. 425 – 435, Aug. 2009.

[6] Martin, F.J.F., Rodriguez, J.C.C., Anton, J.C.A., Perez, J.C.V., Viejo, C.B., Vega, M.G., "An Electronic Instrumentation Design Project for Computer Engineering Students,", IEEE Transactions on Education, vol. 48, issue 3, pp. 472 – 481, Aug. 2005.

[7] Ranaldo, N., Rapuano, S., Riccio, M., Zoino, F., "Remote Control and Video Capturing of Electronic Instrumentation for Distance Learning," IEEE Trans. on Instrumentation and Measurement, vol. 56, Issue 4, pp. 1419 – 1428, Aug. 2007.

[8] R. Manzanares, J. Vázquez, R. Martínez, "Sistema de Entrada / Salida para Didáctica de Microcontroladores y Sistema de Control Remoto Asociado," VIII Congreso TAEE, Tecnologías Aplicadas a la Enseñanza de la Electrónica, Jul. 2008.

[9] Hedley, M., "An undergraduate microcontroller systems laboratory," IEEE Transactions on Education, vol. 41 , issue: 4, Nov. 1998.

[10] Cleaver, T.G., Elbasyouni, L.M., "Student Online Assessment Behaviors," IEEE Transactions on Education, vol. 48, issue 3, pp. 400 – 401, Aug. 2005.

[11] Roscoe S. N., Williges, B. H. "Measurement of Transfer of Training, " Chapter 16 of Aviation Psychology, Iowa State University Press. 1980. Also at http://www.bluecoat.org/reports/Roscoe_80_AvPsych.pdf.

[12] Tuttas, J., Rutters, K., Wagner, B. "Telepresent vs. Traditional Learning Environments –A Field Study". Int. Conf. Engineering Education, Valencia, Spain. 2003.

[13] Lindsay Y, E., Good, M., "Remote, proximal and simulated access to laboratory hardware–a pilot study,". Int.. Conference on Engineering Education, Norway. Aug. 2001.