A “PARTIALLY VIRTUAL” MICROCONTROLLER LABORATORY

Shlomo Engelberg[1] and Cecile Yehezkel[2]
[1]*Department of Electronics, Jerusalem College of Technology, Jerusalem, Israel*
[2]*Bar-Ilan University, Ramat-Gan, Israel*

Keywords: Computer-assisted Instruction, Distance Learning, Virtual Labs, Web Lectures and Notes.

Abstract: In this paper, we describe our experiences running a “partially virtual” microcontroller lab. We show that though the virtual portion of the lab can contribute to the students’ understanding, there are also several pitfalls that must be avoided or dealt with. We have found that our “virtual microcontroller” simulates a true microcontroller to a reasonable extent, but there are cases in which the simulator does not properly simulate the microcontroller. It is critical that students be taught to think of “virtual equipment” as something distinct from the real equipment and as something with idiosyncrasies of its own.

1 INTRODUCTION

At Bar Ilan University, we have been running a microcontroller lab for the last eight years. The lab is a hardware lab – the students use the evaluation kit for the Analog Devices ADuC841 to learn how a microcontroller is used. Both in the labs and at home, the students are expected to use Keil uVision4 integrated development environment (IDE) to write, simulate, and download programs to the microcontroller. The lab manual that the students use (Engelberg, 2012) covers the theoretical material needed throughout most of the course and describes the laboratory exercises that enable the student to learn, practice, and assimilate the theoretical and practical material concerning the microprocessor and its architecture.

When the students prepare for the lab at home, they use the IDE to simulate the microcontroller – to work on a “virtual” microcontroller. In the labs, they continue simulating their system using the IDE, but every project must be downloaded to and work on the actual microcontroller. In this paper, we describe what we have learned about using this combination of real and virtual laboratories to help students understand how an 8052-based microcontroller operates.

2 SIMULATIONS AND VIRTUAL WORLDS

The development and use of simulation are evolving side by side with increases in computing power and advances in multimedia technology. Chaturvedi and Akan (2006) relate that the maturation of computer software technologies such as simulation and visualization has made it possible for engineering designers to analyze and evaluate “what if parametric scenarios” that are intrinsic to the nature of engineering analysis and design processes in the virtual domain. This is creating a new type of engineering – Virtual Engineering. This evolution is influencing both the engineering design process and engineering education. The evolution of simulation and visualization technologies enables implementation of sophisticated features in simulators, such as 3D imaging, "*liveness*" (dynamic immediate visual feedback) (Hundhausen and Brown, 2005), and history recording (Davidovitch et al.,2006).

Simulators are sometimes referred to as visualizations to emphasize the aim of illustrating conceptual models and underlying processes that cannot be seen. Simulation is essential both for researchers and instructors in areas such as quantum computation where the desired system has not yet been implemented

(Barbosa, Lula and Lima, 2007). In these cases, simulation provides a visualization of a theoretical model, and virtual worlds may be created to enable the student to experience the theoretical model. Professional tools for simulation (MATLAB/SIMULINK, LabVIEW, etc.) designed for "virtual engineering" are frequently used by instructors to allow their students to perform laboratory exercises and to introduce them to professional simulation tools. Occasionally educators opt to develop their own simulators to fulfil their needs – needs dictated by the curriculum, the student population, and the constraints of distance learning.

The multitude of simulation and visualization environments and the lack of an appropriate framework to define their characteristics motivated the construction of taxonomies for simulation and visualization. A taxonomy was developed in the domain of program visualizations that emphasized didactic and cognitive aspects based on a very broad taxonomy of software visualization (Price, Baecker and Small, 1998). The main categories of the taxonomy were presentation methods, activity styles, and content modeling. The taxonomy provided a framework for examining characteristics of tools. The designer may opt for a model with high fidelity, a simplified model reduced to the essential characteristics, or a hypothetical model like that used in virtual worlds. As related in (Yehezkel et al., 2007), content modeling has an impact on students' mental models.

Selecting and illustrating an appropriate conceptual model for the simulator are essential for ensuring a fruitful learning process. The simulator must be part of a course covering the comprehensive theoretical material on the conceptual model, illustrating the material by using the simulator and other activities that enable the student to practice and assimilate the new concepts.

3 INSTRUCTIONAL DESIGN

The design of new educational simulators should be learner-centred and accompanied by formative evaluation, and such designs require developing methodologies to evaluate their effectiveness (Donzellini and Ponta, 2007); (Ma and Nickerson, 2006); effectively evaluating simulator utilization in education is essential for further improvements. Chaturvedi and Akan (2006) claim that simulation and visualization have great potential to enhance student learning and the quality of engineering education. They believe that the desired objective is for students to achieve a deeper understanding of basic principles. They define the characteristics essential for effectiveness as *interactivity* (between the student and the environment), *interconnectivity* (between subject materials), and *hierarchy* (gradual learning with succeeding modules). In (Engelberg, 2012), we have been careful to make sure that our labs are interactive, connected, and proceed from simple labs to acquaint the student with individual features of our microcontroller to more complicated labs in which the student must make use of several features to accomplish the task which was set.

The learning process cannot be generated by the simulator, the visualization, or the virtual world. Simulation-based activities are required to create a fruitful interaction between the learner and the simulator. In (Veermans and de Jong, 2000), the authors emphasize the importance of both model progression and gradually increasing the complexity of assignments to guarantee the effectiveness of simulation-based learning. A well-designed educational environment based on a simulator should support each component of this approach. Simulation-based learning must be supported to help the learner acquire skills and meta-skills and to deepen his or her understanding of the underlying processes illustrated by the simulator. According to Feisel and Rosa (2005), the early criticisms of simulations focused on the rigidness of simulations, the lack of realism in models, or on simulated results that did not adequately represent real-world systems and behavior, therefore causing the designer to tend to emphasize the realistic aspects of simulation-based learning activities. Recently, Ma and Nickerson (2006) have made a comparative review of the literature related to hands-on, simulated, and remote laboratories in education. They have observed that the boundaries among the three types of environments are blurred in the sense that most laboratories are mediated by computers and that the psychology of presence may be as important as the technology. They conclude that with the proper mix of technologies one can find solutions that meet the economic constraints of laboratories by using simulations and remote labs to reinforce conceptual understanding while at the same time providing enough open-ended interaction to teach design. By making judicious use of the IDE while requiring that every program run on the evaluation kit, we believe that we have achieved this goal.

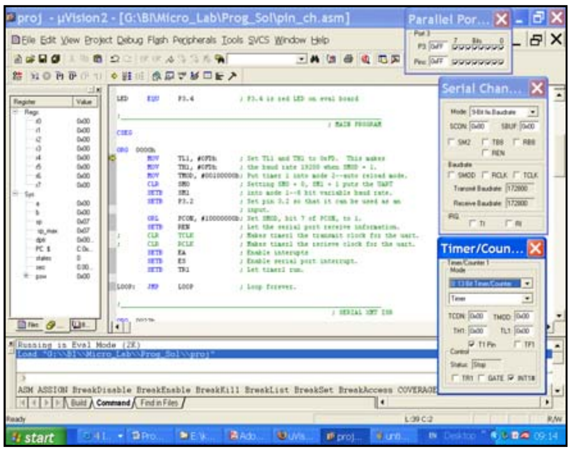
In section 4 we present the features of the IDE, and in section 5 we explain the motivation for the use of virtual microcontrollers. In section 6, we describe the problems caused by the lack of the fidelity of the model implemented by the IDE, and in section 7, we summarize our conclusions.

4 THE IDE AND THE ADUC

The IDE we use is the Keil uVision4 IDE. It is one of the standard IDEs for microcontrollers from the 8051 family. The IDE provides many tools including a simulator/debugger and a downloader that allows one to download a program from the IDE to the microcontroller.

The ADuC841 is a microcontroller whose instruction set is based on that of the 8052. The development kits sold by Analog Devices include everything one needs to run a program. As a rule the development kit is a pleasure to work with.

The simulator/debugger allows one to run a program and examine the program as it executes. As shown in Figure 1, one can simulate using most of the ADuC841's peripherals – though using some of the less standard non-8052 peripherals can be something of a challenge. (It can be difficult to simulate complex input to the analog to digital converter, for example.)


proj - µVision2 - [G:\BI\Micro_Lab\Prog_Sol\pin_ch.asm]

```
LED     EQU     P3.4            ; P3.4 is red LED on eval board

;________________________________________ ; MAIN PROGRAM
CSEG

ORG  0000h
        MOV     TL1, #0FDh      ; Set TL1 and TH1 to 0xFD.  This makes
        MOV     TH1, #0FDh      ; the baud rate 19200 when SMOD = 1.
        MOV     TMOD, #00100000b; Put timer 1 into mode 2--auto reload mode.
        CLR     SM0             ; Setting SM0 = 0, SM1 = 1 puts the UART
        SETB    SM1             ; into mode 1--8 bit variable baud rate.
        SETB    P3.2            ; Set pin 3.2 so that it can be used as an
                                ; input.
        ORL     PCON, #10000000b; Set SMOD, bit 7 of PCON, to 1.
        SETB    REN             ; Let the serial port receive information.
;       CLR     TCLK            ; Makes timer1 the transmit clock for the uart.
;       CLR     RCLK            ; Makes timer1 the recieve clock for the uart.
        SETB    EA              ; Enable interupts
        SETB    ES              ; Enable serial port interrupt.
        SETB    TR1             ; Let timer1 run.

LOOP:   JMP     LOOP            ; Loop forever.

;________________________________________ ; SERIAL XMT ISR
```

```
Running in Eval Mode (2K)
Load "G:\\BI\\Micro_Lab\\Prog_Sol\\proj"
```

File Edit View Project Debug Flash Peripherals Tools SVCS Window Help
Parallel Port
Serial Channel
Timer/Counter
ASM ASSIGN BreakDisable BreakEnable BreakKill BreakList BreakSet BreakAccess COVERAGE
Build
Command
Find in Files
start

Figure 1: The IDE simulator / debugger.

5 WHY WE USE VIRTUAL MICROCONTROLLERS

At present, approximately 100 students are required to participate in the microcontroller laboratory every year. It would probably be best to have students work alone and to give each student a microcontroller to work with. In practice, our students work in pairs, and while they are in the lab they have access to one of the approximately 25 development kits. (The lab is run in several sections.) For a variety of reasons, the labs are not freely accessible to the students outside of class time, so students have access to actual development kits for a period of about three hours each week.

Students work in pairs for a variety of reasons. Working in this way teaches them how to work in a team. It also keeps the cost of the course within reasonable limits by requiring fewer instructors. (In order to see to it that the students are learning proper programming practices, all programs are checked and corrected. By having the students work in pairs, fewer instructors can take care of the grading.)

The demo version of the Keil uVision4 IDE is freeware. It is given out with the ADuC841 evaluation kits, and it is available on Keil's website (https://www.keil.com/demo/eval/c51.htm). By using virtual microcontrollers – by using the IDE's simulator and debugger – we are able to provide each student with his or her own microcontroller. Students can work on their virtual microcontroller when and where it suits them. Because the program is free, every student can have a "virtual microcontroller."

A signal advantage of the IDE is that it gives the user easy access to many things to which there would otherwise be no (easy) access. If a student wants to learn how an arithmetic command works, it is simple to program the IDE to use the command. Because the IDE allows the user to look at all of the microprocessor's registers, the user can quickly find out just how a command affects the microprocessor. This is something that is much more easily done with and IDE than with a true microprocessor. Given all of its advantages, why not make a course that only uses "virtual microcontrollers?"

6 THE PROBLEMS WE HAVE EXPERIENCED WITH THE VIRTUAL MICROCONTROLLERS

There are several problems with using a virtual microcontroller. As with all virtual equipment, there is a danger that the user will not understand which parts of the equipment being used are real and which parts are virtual. Additionally, there are often actual problems with the virtual systems; there are places that the virtual system does not faithfully mimic the physical system.

6.1 Problems with *any* IDE

Years ago, when designing the lab, we had to decide what environment to use when programming. Initially, we had the students write program using a *very* simple editor (either Notepad or Edit). We had the students compile the program using a separate compiler, and we had them download the programs using a separate downloader provided by Analog Devices. We did this to help the students understand what the role of each component was.

Because professionals generally use IDEs, after a year or two we changed the structure of the lab somewhat. We started off using separate programs, but after a few weeks we had the students use the IDE. In this way the students got used to thinking about the roles of each of the separate programs and were exposed to a reasonably standard IDE.

Several years ago, we found that Windows would not allow us to use the older style programs, and we started using the IDE exclusively. The disadvantage of the increased use of the IDE, of the virtual system, is that some of the students have a hard time determining which of their commands are going to control the virtual system and which are commands that are, fundamentally, commands to the microcontroller. Additionally, using an IDE, with all its many menus, can cause a student to assume that using a microcontroller is much more complicated than is actually the case. We spend quite a bit of time trying to dispel this illusion. At the beginning of the course, we make almost no use of the advanced features provided by the IDE. After the students understand the microcontroller, we give a fairly detailed description of the IDE and its features. In this way, the students learn to distinguish between the microcontroller and the debugger provided by the IDE.

6.2 Problems with *our* Virtual Microcontroller

There is a second problem with using the IDE, the virtual microcontroller – it does not always simulate the microcontroller 100% faithfully. This problem is (predictably) most severe when one is using features that are not used that often or when there is a somewhat complicated interaction between the program one is writing and the hardware that one is trying to control. All of the examples here are from our experience using uVision3 V3.33.

Users of the 8052 will be familiar with the “read-modify-write” commands (MC51 user’ s guide). When such commands are used to read and modify values of pins of an I/O port, they read and write to the input latch to the I/O port and they do not “look at” the voltage currently “seen” by the port (shown in Fig. 1). Most other commands look at the current voltage seen by the port.

The command `JBC PM.N, label`, which causes the microcontroller to examine the Nth pin of the Mth I/O port, jump if the bit is a one and clear the bit, and continue if the bit is a logical zero, is a read-modify-write command. This command *ought* to look at the value of the latch connected to this pin’s input. (That is, it ought to react to the last value written to PM.N.) On the actual microcontroller, this is exactly what happens.

The IDE’s simulator is rather easy to use, and it is possible to tell the simulator that a bit’s latch is set – that the last input to the pin was a logical one – but the voltage on the pin is actually 0V. If one does this, then even when using the JBC command, which ought to look at the value of the latch, the command looks at the actual (simulated) voltage on the pin and behaves in a fashion that is neither consistent with the commands definition nor with what the microcontroller actually does. A student using the IDE is likely to be very confused by this. (It is worth noting that in later versions of the IDE this problem was corrected.)

Another interesting problem of this sort is encountered when one uses Timer3, a timer that was added to the ADuC841 and that can be used as the clock for the 8052-standard UART. One of the registers that controls this timer is the T3FD register. From our experience, it seems that the permitted values of this register are not all the values that one can write to the register. When one writes an illegal value, the IDE shows the microcontroller working as “it ought to” when the microprocessor actually works in a somewhat different fashion.

A student who uses the IDE might confuse him or herself by trying to watch how the ADuC841 physically transmits data by either using the parallel port dialog box (shown in Fig. 1) to watch the pin on which the data leaves the ADuC841 – which is physically the same pin that is used by pin 1 of port 3, P3.1 – or by using the simulated logic analyzer provided by the IDE to watch P3.1. Unfortunately, neither of these methods will actually allow the student to see how the UART works. Though a ‘scope probe held to P3.1 will show the student the relevant voltages, the IDE does not consider the UART’s transmit pin and P3.1 to be the same.

Years ago we used the ADuC812 in our lab. This microprocessor is very similar to the ADuC841, but we experienced an interesting anomaly with the ADuC812 that does not exist with the ADuC841. When a program was run after being directly downloaded from the IDE to the ADuC812, sometimes the program would run when it should not have. This would happen because the ADuC812 does not finish a download with all of its registers reset to their default values (Analog Device Technical notes). In particular, it leaves a timer running that is turned off after a reset. Students would forget to turn on the timer in their program, would find that their program worked on the microconverter but not in simulation, and would hand in the programs not understanding what had happened. A somewhat different problem with our IDE is how it simulates non-ADuC devices. The IDE has the ability to simulate the “other side” of a UART. One can ask the IDE to open a window that behaves very much like the Windows “HyperTerminal” program that allows one to communicate using the (virtual) P.C.’s (virtual) serial (COM) port. The problem with the window opened by the IDE is that it automatically adjusts itself to whatever baudrate the user has, in fact, selected. If the user meant to select a baudrate of 19,200 symbols/sec but in fact selected 1,200 symbols/sec, the “HyperTerminal” window will show perfect communications. When the user downloads the program to the microcontroller, it may take a fair amount of time for him/her to realize where the mistake was. Here one cannot say the simulator did not work correctly. It worked correctly but allowed the user to fool him or herself.

7 LESSONS WE HAVE LEARNED

After working with various simulation tools, one realizes that they have advantages and disadvantages. The simulation tools may be more accessible than the physical system being simulated is. The simulation tools may allow one to observe things that would otherwise be difficult or impossible to observe. The tools may also be less expensive than the physical system. For these reasons one uses the tools.

When one uses simulation tools intensively, one realizes that they must be considered a separate type of “equipment.” Just as standard physical systems have their personalities, their quirks, so do simulators and virtual equipment. During an engineer’s working lifetime, the engineer will have to learn to work with many types of equipment, and it will be necessary to understand the idiosyncrasies of each piece of equipment.

An experienced engineer should not have a problem distinguishing between the properties of a simulator and the properties of an actual piece of equipment. When working with students, however, it is not as certain that the students will manage to make the distinction. For this reason great care must be exercised when running a lab on equipment other than the actual industry-standard equipment.

In our microcontroller lab, much effort is expended in order to help the students understand what a “virtual microcontroller” is and what a real microcontroller is. As long as we succeed in making that distinction clear, we are helping our budding engineers understand the tools of the trade – both “virtual equipment” and “real” equipment. That is, of course, our goal.

ACKNOWLEDGEMENTS

Many people have contributed to the microcontroller lab over the years. We are particularly grateful to Prof. Aryeh Weiss of Bar Ilan University who has supported the lab from its outset and to the members of our team – Messrs. Tamir Rozental, Shai Tamir, Amikam Borkowski, Amihai Meiri, and Aviram Gur.

REFERENCES

Analog Devices, “MicroConverter Technical Note - uC004 Understanding the Serial Download Protocol,” Analog Devices, Inc., Norwood, MA, 2001.

Barbosa, A. Lula, B. and Lima, A. F., 2007. Symbolic and numeric quantum circuit simulation, *Proceedings of the 1st International Conference on Quantum, Nano, and Micro Technologies (ICQNM'07)*, pp. 6-10.

Chaturvedi, S. K. and Akan, O., 2006. Simulation and Visualization Enhanced Engineering Education, *International Mechanical Engineering Education Conference*, Beijing, China.

Davidovitch, L. Parush, A. and Shtub, A., 2006. Simulation-based Learning in Engineering Education: Performance and Transfer in Learning Project, *Journal of Engineering, American Society for Engineering Education, Oct.*, pp. 289-300.

Donzellini, G. and Ponta, D., 2007. A Simulation Environment for e-Learning in Digital Design, *IEEE Transactions on Industrial Electronics*, vol. 54, no. 6, pp. 3078-3085.

Engelberg, S. 2012. *ADuC841 Microcontroller Design Manual: From Microcontroller Theory to Design Projects*, Circuit Cellar, Vernon, CT, to appear.

Feisel, L. D. and Rosa, A. J. 2005. The role of the laboratory in undergraduate engineering education, *Journal of Engineering Education*, vol. 94, no. 1, pp. 121–130.

Hundhausen, C. D. and Brown, J. L. , 2005. What you see is what you code: a radically dynamic algorithm visualization development model for novice learners, *Proceedings of the 2005 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC'05)*, pp. 163-170.

Ma, J. and. Nickerson, J. V., 2006. Hands-on, simulated, and remote laboratories: A comparative literature review, *ACM Computer Survey*, vol. 38, no. 3, pp. 1-24.

MCS51 Microcontroller Family User's Guide, Intel Corp., Mt. Prospect, IL, 1994, p. 3-9.

Price, B. A. Baecker R. M. and Small, I. ,1998. An introduction to software visualization. In J. Stasko, J. Domingue, M. Brown & B. Price (Eds.), Software Visualization, pp. 3-34, Cambridge, MA: MIT Press.

Swaak J. and de Jong, T., 2001. Discovery simulations and the assessment of intuitive knowledge, *Journal of Computer Assisted Learning*, vol. 17, no. 3, pp. 284-294.

Veermans, K. H. de Jong, T. van Joolingen, W.R., 2000. Promoting self directed learning in simulation based discovery learning environments through intelligent support. *Interactive Learning Environments*, no. 8, pp. 229-255.

Yehezkel, C. Ben-Ari, M. and Dreyfus, T., 2007. The contribution of visualization to learning computer architecture, *CSE on Special Issue on Teaching Hardware-software*, vol. 2, no. 17, pp. 117-127.