Integration of an Online Digital Logic Design Lab for IT Education

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ABSTRACT
Digital electronics is a fundamental course in electrical engineering and many information technology programs, as well as most other science programs. In this paper, we present web-based system aimed at teaching logic design concepts and practices for computer science and engineering students implemented using LabVIEW. Experiments, which include digital logic gates, combinational logic circuits, seven segment display, sequential logic and counters are easily constructed and performed, both in traditional and online setups. This course is as an example of how to integrate a combination of theory and lab experiments simultaneously in a blended learning environment, where lectures can present the material for students to access, and at the same time perform the experiments online into the curriculum.

Categories and Subject Descriptors
J.2. [**Physical Sciences and Engineering**]: Electronics and Engineering

General Terms: Measurement, Design, Experimentation.

Keywords: IT Education, Digital Electronics, Remote Labs, Combinational Logic, Sequential Logic, LabVIEW

1. INTRODUCTION
With the worldwide availability of computers and the Internet, academic education has taken on vast new dimensions, including internet based education and research. Particularly, information technology and engineering education is becoming an exciting emerging field of research involving a multitude of disciplines aiming to resolve the pedagogical challenges, which are arising with the advancement of technology. Laboratory equipment is becoming sophisticated, yet too expensive for each individual university to purchase and maintain. Virtual and remote laboratories offer a solution and represent a practical alternative allowing students of different institutions to conduct experiments online, anywhere, and anytime, using the facilities of one designated university hosting these setups.

Digital electronics is one of the fundamental courses in electrical engineering and many information technology programs, as well as most other science programs. Experiments, which include digital logic gates, combinational logic circuits, seven segment display, sequential logic and counters are easily constructed and performed, both in traditional and online setups. This course is as an example of how to integrate a combination of theory and lab experiments simultaneously in a blended learning environment, where lectures can present the material for students to access, and at the same time perform the experiments online into the curriculum.

We present a web-based system aimed at teaching logic design concepts and practices for computer science and engineering students. The online lab was implemented using LabVIEW programming language because it is best suited for the project's purposes due to its straightforwardness and serviceability, fast development times and the ability to create stand-alone executables. Design, architecture, and instructional method are outlined as well as the implementation of this classroom-lab course, utilized by electrical engineering students at Princess Sumaya University for Technology, which will serve as a hub for other universities in the region and abroad.

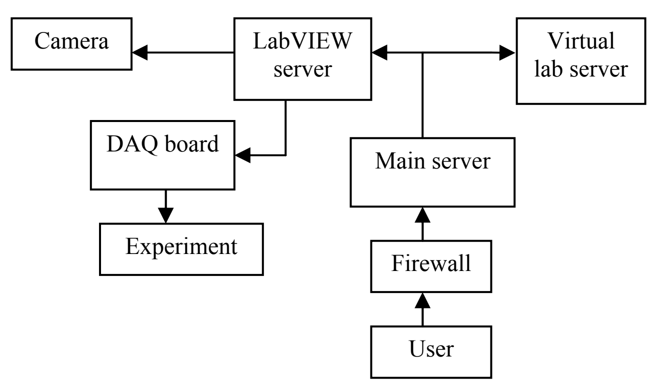

Figure 1: Schematic of the Internet based tutoring system

2. REMOTE AND VIRTUAL LABS

2.1 Remote Laboratories

Remote experiments are real experiments, remotely controlled by the student from outside the laboratory. A Remote Experiment consists of two vital parts, namely the experiment itself and a computer interface allowing control over the experiment via the internet. For the latter, we use National Instruments LabVIEW [1], which also provides a convenient web-interface. In order to view and control the experiment, the students can download and install a freely available web browser plug-in. Due to the modular programming structure of LabVIEW, remote experiments can easily be combined or extended [2, 3, 4]. A new way in e-Learning is a virtual laboratory, where a simulation system commonly replaces the real system. A remote lab is a combination of hardware and software designed to enable students to access various laboratories from their homes, libraries, or even other countries. Not all universities have the same facilities, so remote labs give engineering, IT, and science students in general the opportunity of virtually conducting and participating in sophisticated experiments. Using the remote lab in such situations not only saves time and money, but also gives results that are more accurate from the very first try.

2.2 Virtual Laboratories

Virtual laboratories typically originate from computation and simulation software such as Matlab [5] or LabVIEW [1]. Yet, one has to take care that such software can also be used for real system control.

Remote experiments and virtual laboratories are actively used in various experimental sciences. Related training courses have also been explored in chemistry, see e.g. [6] and electrical engineering, e.g. by [7]. Other interesting setups include the remote experiment and virtual lab for wind tunnels developed by Esche et al. [8], a virtual laboratory for exploiting DSP algorithms [9], and a learning tool for chip manufacturing [10]. Virtual labs are also explored as on-shore educational tool to train the technical skills of sailors of the US navy, see [11].

2.3 Implementation

In this paper, we describe how we designed and implemented a remote lab at Princess Sumaya University for Technology. The remote lab may consist of any experiment that can be connected to a computer server and eventually virtualized. In the following remote labs are discussed in detail, explaining different experiments and their results. The experiments conducted are prepared with the Logic and Organization Lab, which is available online.

We used National Instruments "LabVIEW" together with the NI "ELVIS" [12] to assemble and create this project. This prototyping platform is a prerequisite for all the experiments, ELVIS and LabVIEW go hand in hand. The remote lab is designed to provide real-time experiments to students via the Internet. A schematic of the various components of the tutoring system is depicted in Figures 2 (a-d). The main server (for a schematic of the tutoring system cf. figure 1) houses the core of the tutor, including support materials for help sessions, and animation. Either the virtual lab or a real-time remote lab can provide the experiments. Graphical G (NI) programming software is used together with its Internet Toolkit to implement the virtual and the remote labs.

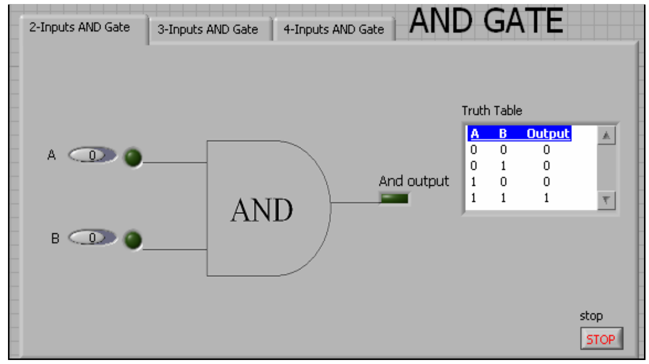

Figure 2(a): 2-Input AND gate

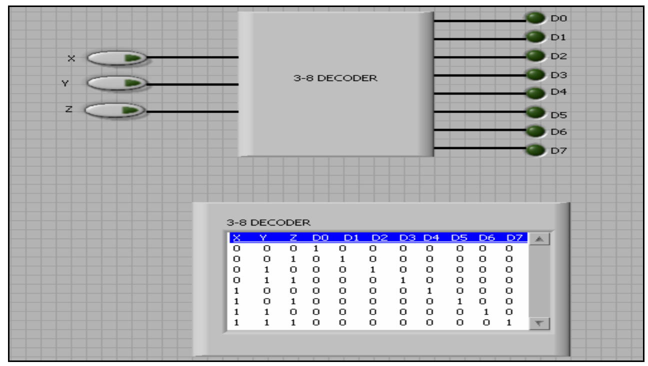

Figure 2(b): 3-8 Decoder

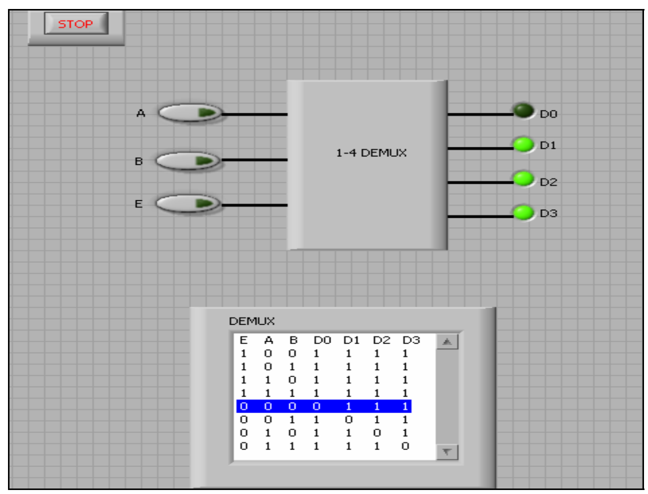

Figure 2(c): 1X4 Multiplexer

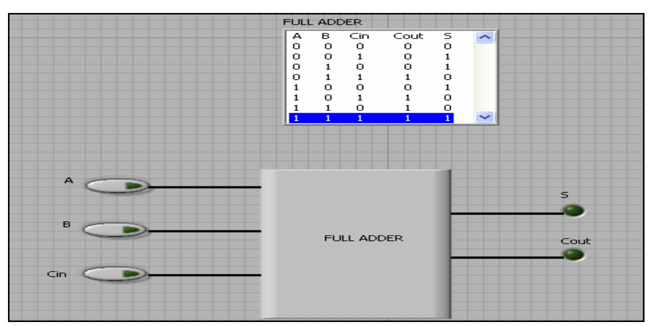

Figure 2(d): 1-bit Full Adder

A data acquisition (DAQ) board accomplishes control of instruments and acquisition of data. The processes are summarized in figs. 3(a-d) Specific components of the block diagram for electrical and other experiments, can be found in [13, 14].

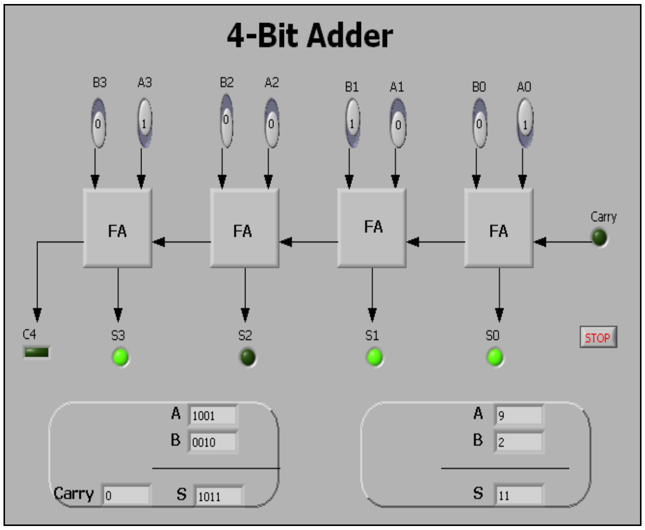

Figure 3(a): 4-Bit Adder

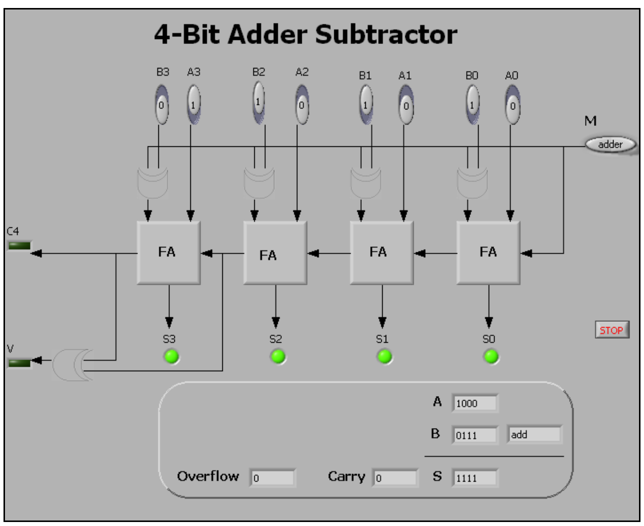

Figure 3(b): 4-Bit Adder Subtractor

The LabVIEW Web Server is used to publish images of front panels on the Web. By default, after the Web Server is started all VIs are visible to every Web browser. However, access can be limited to the published front panels and the visibility of VIs on the Web can be adjusted. For displaying front panels on the Web, the VIs must be in memory on the client computer. The Web Publishing Tool is used to create an HTML document and embed static and animated images of the front panel. Images can also be embedded in an existing HTML document.

3. DESIGN OF COMBINATIONAL LOGIC

Digital electronics [15] is one of the fundamental courses found in all electrical engineering and most science programs. The broad variety of LabVIEW Boolean and numeric controls/indicators, together with the wealth of programming structures and functions, make LabVIEW an excellent tool to visualize and demonstrate many of the fundamental concepts of digital electronics. The inherent modularity of LabVIEW is exploited in the same way that complex digital integrated circuits are built from circuits of less complexity, which in turn are built from fundamental gates.

The experiments are implemented and published on the web using LabVIEW. These experiments are:

1. digital logic gates,
2. combinational logic circuits,
3. seven segment display,
4. sequential logic, and
5. counters.

After they have been published, the experiments can be accessed and controlled remotely via the internet.

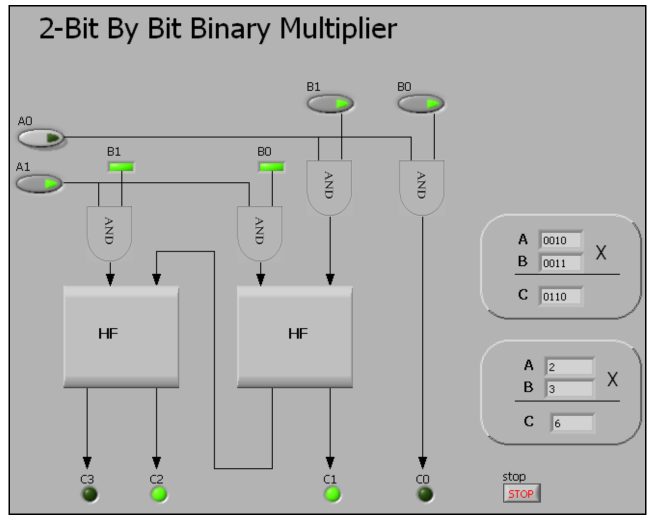

Figure 3(c): 2 Bit by Bit Binary Multiplier

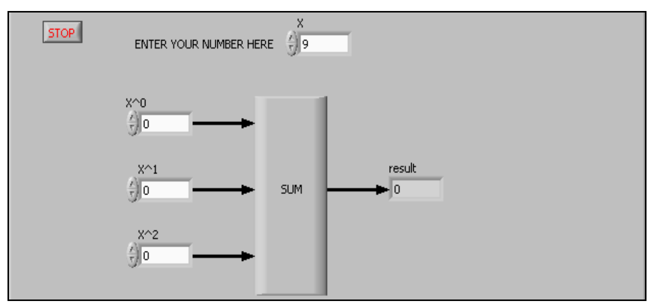

Figure 3(d): Mathematical Example

A number of basic logic gates and other chips are virtually assembled to form a logic design lab using LabVIEW software. These include inverters, *AND, NAND, OR, NOR, XOR, XNOR* gates, in addition to decoders (cf. figure 2(b)), encoders, multiplexers (cf. figure 2(c)) and demultiplexers, full adders (cf. figure 2(d)), 7-segment decoders, a 4-bit arithmetic-logic unit (ALU), flip-flops and counters.

The AND gate (cf. figure 2 (a)) has two or more input signals which can by toggling be a Boolean switch. Because the AND gate is provided as a basic built-in LabVIEW function, two switches are connected to the gate inputs and an indicator LED to the output to produce a simple VI (virtual instrument) that demonstrates the AND gate. The truth table is demonstrated by wiring the input switches to a "build array function" which is wired to a "Boolean array to number converter" as shown in figure 2(a). Similar procedures are followed with other gates. In addition, combinational circuits such as 1X4 multiplexer, 3X8 decoder, 1-bit full adder and all their derivatives are designed as shown in the example of figure 2 (b-d).

Furthermore, we constructed a binary adder with full adders connected in cascade, with the output carry from each full adder connected to the input carry of the next full adder in the chain. We aligned four full adders in order to provide a 4-bit binary ripple adder. Each two bit inputs (*Ai* and *Bi*) are represented by switches, wired to a full adder sub *VI*, and two indicators to the output, one is a LED for the sum (*Si*) and the other is wired to the next (*FA*). The output of the last *FA* is the carry *Ci*, indicated by a LED. The output is represented in three forms, the binary indicator, the decimal indicator, and the LEDs, as shown in figure (3a).

Furthermore it is certainly reasonably to modify the adder circuit to perform either addition or subtraction (depending on a control input) to form a simple ALU (Arithmetic Logic Unit). The operation is selected by a control input selection line, *S*. Accordingly, a binary adder-subtractor was designed with full adders, with a mode input control. The circuit produces two outputs, *C* and *V*. If the two binary numbers are unsigned, the *C* bit identifies a carry after addition or a borrow after subtraction. If the two binary numbers are signed, the *V* bit identifies an overflow. Figure 3(b) shows the 4-bit adder-subtractor. A binary multiplier is subsequently constructed with two half adders connected together in cascade, as shown in figure 3(c). The inputs (*Ai* and *Bi*) are identified by switches that are wired to half adders through AND gates, and the output is represented by indicators LEDs; *C0*, *C1*, *C2* and *C3*. The output is represented in two forms as well; the binary indicator and the decimal indicator. A mathematical block was finally included in the design to perform additions of numbers of base *x*, to the power 0, 1, 2, as depicted in figure 3(d).

4. ARITHMETIC-LOGIC UNIT

An arithmetic-logic unit [16] performs many different arithmetic and logic operations as shown in figure (4). This 8-bit ALU performs arithmetic which include addition, subtraction, decrement, increment and logic operations which include inversion, AND, OR, XOR, etc. The selection lines *Si* are used to select the required operation, thus forming what may be referred to as the machine language of the ALU.

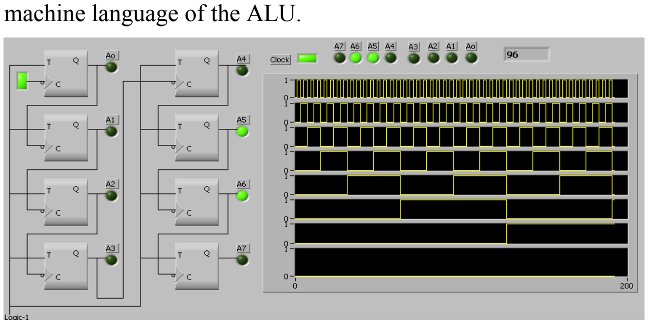

Figure 4(d): 8 bit counter.

The user can easily interact with this interface through the input switches (manually) or by entering any number automatically, and the results will be displayed on the lower rectangle. (*S*, carry, overflows). A hardware chip is also controlled remotely via the ELVIS. Data input is entered and a specific operation is chosen through the selection lines to perform addition, subtraction, .etc. Data is first transmitted to the chip, through a "write operation", the output is then received from the chip through a "read operation", and the output is finally displayed on the interface.

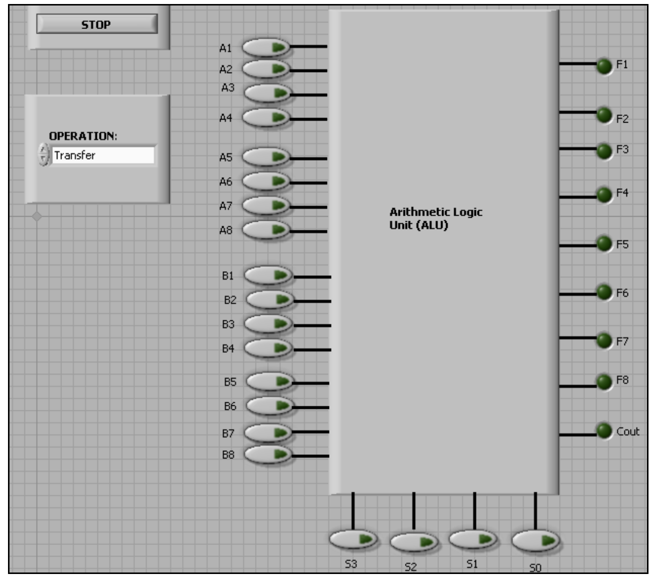

Figure 4(a): 8-bit virtual ALU.

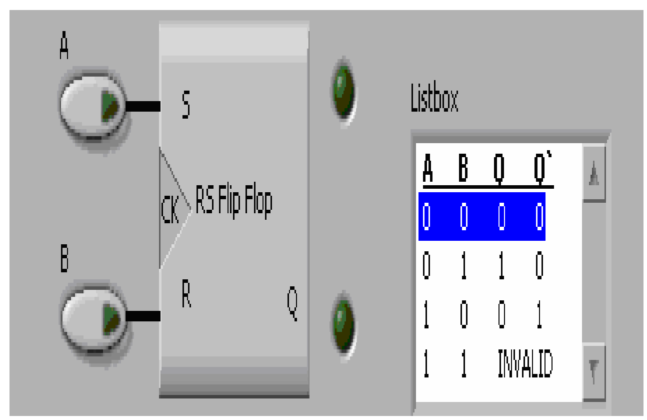

Figure 4(b): SR flip-flop.

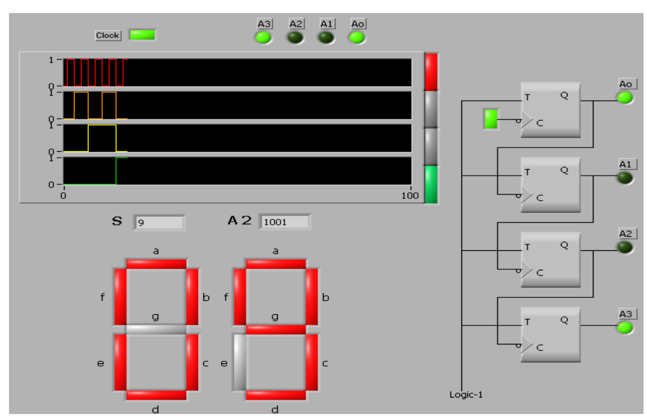

Figure 4(c): 4 bit counter

5. SEQUENTIAL LOGIC

An SR or "set/reset" flip-flop is triggered to a high state at *Q* by the "set" signal and holds it until the reset signal is set to low by the Reset input. It can be constructed from a pair of cross-coupled NOR logic gates. The stored bit is present on the output *Q*. In LabVIEW, the SR flip-flop is constructed using switches as Boolean inputs wired to two NOR gates. A Boolean LED indicator can indicate an output for both outputs *Q* and *Q'*. The T flip-flop sub-VI is used inside of a while loop with shift registers. The four binary states (*A3, A2, A1, A0*) for the 4 bit counter and the eight states (*A7, A6, A5, A4, A3, A2, A1, A0*) for the 8-bit counter are displayed as LED indicators, and the decimal equivalent value as a numeric on the front panel. In the 4-bit counter the output is connected to two seven segment display sub-VIs.

In the 4-bit counter and the 8-bit counter, T flip-flops are used. The output of each flip-flop changes state on the falling edge of the T input. In the 4-bit counter the binary count held by the counter runs from 0000 to 1111. The next clock pulse will cause the counter to try to increment to 10000 (decimal 16). However, that 1 bit is not held by any flip-flop and is therefore lost. As a result, the counter actually reverts to 0000, and the count begins again. In the 8-bit counter the binary count held by the counter runs from 00000000 to 11111111.

6. CONCLUSION AND OUTLOOK

A remote lab was successfully designed and constructed at Princess Sumaya University for Technology consisting of a number of experiments, connected to a dedicated computer server. The remote lab is designed using LabVIEW and then published onto the web at www.iLab.psut.edu.jo.

The project's long-term objective is to become a hub for other universities in Jordan and the region to utilize its facilities through conducting a multitude or remote lab experiments. The project should eventually give an insight onto the future advancement of educational systems worldwide as we are approaching a new revolutionary age of advanced technology. The authors recently started connecting the remote experimentation facilities at PSUT and TU Berlin to make the experiments available to students of both universities.

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