

New Dimensions in Teaching Digital Electronics: A Multimode Laboratory Utilizing NI ELVIS II™, LabVIEW and NI Multisim

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Abstract—Over the years, conventional Laboratories in African Universities have been hampered by inadequate resources in terms of the required hardware, space and skilled personnel to administer them. This paper describes a multi-dimensional approach to experimentation, developed by the Makerere University iLabs Project Team, hereafter referred to as iLABS@MAK. The two dimensional approach involves both Virtual Labs and Online Laboratories designed to address laboratory deficiencies in Digital Electronics, encompassing five courses in the curricula of the Bachelor of Science (B.Sc) in Computer, Electrical and Telecommunication Engineering Programmes. A digital Online Laboratory, the Makerere University Digital iLab (MDEi) supporting experiments in the fields of combinational logic circuits and asynchronous sequential logic circuits has been developed. The laboratory utilises the National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS II™) platform, the Laboratory Virtual Instrument Engineering Workbench (LabVIEW) graphical programming environment and NI Multisim. Typical experiment setups supported by the MDEi are presented.

Index Terms—Digital Electronics, Digital Reader, Digital Writer, Online Laboratory, Virtual Instruments.

I. INTRODUCTION

The role of experimentation in technical education cannot be overemphasized. The laboratory experience adds a dimension that allows students to appreciate theoretical concepts and gain valuable career skills. The rapid changes in technology pose a continual need to update and augment laboratory work to keep pace with this trend [1]. Laboratories can be administered in either of three forms: conventional laboratories where students and researchers have hands-on access to equipment, virtual laboratories which involve simulations, and Online Laboratories, where users operate and control physical equipment remotely through a suitable user interface [2].

The effectiveness of conventional laboratories in several African Universities is inhibited by inadequate infrastructure, including unmatched equipment vis-à-vis the user community, and also in many cases the infrastructure being obsolete. This leads to laboratory scheduling problems which renders the laboratory experience insufficient in meeting the students' and researchers' needs. Under the circumstances, the most plausible solution is to use computer based laboratories i.e. virtual laboratories or Online Laboratories. Virtual laboratories, though providing an alternative to conventional laboratories, do not avail an interface to the physical world. An Online Labo-

ratory on the other hand involves the use of physical hardware hence the experiment data is real while the laboratory experience is simulated. This approach provides an opportunity to address the planning and logistics challenges associated with inadequately furnished conventional laboratories. Online Laboratories offer a flexible and convenient user experience for researchers and students facilitating effective utilization of would be meager resources.

The Faculty of Technology at Makerere University (MAK) adapted the iLabs Shared Architecture (ISA), one of the existing instances of Online Laboratories developed by scholars at Massachusetts Institute of Technology. The ISA is a web service infrastructure that supports access to a wide variety of online laboratories [3]. It consists of three software tiers: the Labserver, which provides a physical connection to the laboratory hardware, the Client (user interface) and the Service Broker which mediates communication between the Labserver and Client, and provides generic services like user registration and authentication. Developers of new laboratories can take advantage of the ISA scalability, without re-inventing the wheel for generic services, especially regarding laboratory administration.

On the ISA platform, an Online Laboratory supporting Digital Electronics courses for the Bachelor of Science (B.Sc) Programmes in Computer, Electrical and Telecommunications Engineering has been developed by researchers at MAK. The MAK Digital Electronics iLab (hereafter referred to as MDEi) supports experiments in the fields of combinational logic circuits and asynchronous sequential logic circuits. MDEi utilizes version 1.0 of the Batched ISA. The Laboratory is set up on the National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS II™) hardware. The NI ELVIS II™ integrates hardware and software to shrink the electronics laboratory to only two elements; the experiment interface and the computer [4], and contains twelve laboratory instruments (Function Generator, Oscilloscope, Digital Multimeter, Dynamic Signal Analyzer, Bode Analyzer, Digital Reader, Digital Writer, Variable Power Supply, Arbitrary Waveform Generator, Impedance Analyzer, Two-Wire and Three-Wire Current-Voltage Analyzers). The instruments of relevance in the MDEi are the Digital Reader and the Digital Writer.

The Digital Writer is used to input user-defined logic data to the circuit set up on the NI ELVIS II™ free scale prototyping board while the Digital Reader outputs the data resulting from the specific logic circuit of interest set

up on the board. On a local computer, the instruments are available in software form as soft front panels. To facilitate remote access in the MDEi, the instruments had to be custom-programmed using the Laboratory Virtual Instrument Engineering Workbench (LabVIEW), a graphical programming language. To enrich the laboratory experience even further, the laboratory involves preparatory assignments in LabVIEW and NI Multisim, a circuit simulation tool.

II. THE MAK DIGITAL ELECTRONICS ILAB (MDEI)

The study of Digital Electronics is fundamental in the training of Computer, Electrical and Telecommunications Engineering students. In this respect, six courses are offered in the undergraduate curricula for the BSc. in Computer, Electrical and Telecommunication Engineering Programmes at the Faculty of Technology at MAK as shown in Table I. The smooth running of these programmes is challenged by inadequacies in the infrastructure needed to support the requisite conventional laboratories. The students enrolment statistics for Programmes of Bachelors of Science in Computer, Electrical and Telecommunications Engineering are shown in Table II, with line totals indicative of the demand for Digital Electronics Laboratories. It is important to note that in the three

programmes, all first and second year courses are core. With inadequate laboratory infrastructure, these students are not able to enjoy a rich laboratory experience.

The iLabs Project at Makerere University (iLabs@MAK) based at the Faculty of Technology acquired Online Laboratory infrastructure that has been used to develop the MDEi. This infrastructure includes among others, the ISA software toolkit, the NI ELVIS II™, LabVIEW and NI Multisim. The infrastructure has not only been used to develop Online Laboratories supporting Digital electronics but relevant course assignments as well.

In development of the online laboratory, a custom Virtual Instrument (VI), a LabVIEW program, incorporating the functionalities of the Digital Reader and the Digital Writer was built in LabVIEW. The VI was compiled into a .NET library and used in the Labserver as a driver for the NI ELVIS II™ instruments to execute the experiments on the hardware. Relevant changes were made in the Labserver source code to enable parsing, execution, retrieval and graphing of digital data. A java applet client to provide a graphical display of the logic inputs and outputs in form of timing diagrams was developed. The subsequent sections present a synopsis of the different use cases supported by the MDEi.

TABLE I.
DIGITAL ELECTRONICS EXPERIMENTATION FIELDS AT MAKERERE UNIVERSITY [5]

Year	Programme	Course	Topics
I	BSc. Electrical Engineering	ELE 1201: Introduction to Digital Electronics	Logic Gate Characteristics, Minimization Techniques, Combinational Logic Circuits (Adders, Multiplexers, Encoders, Decoders, Seven Segment Displays), Sequential Logic Circuits (Latches, Flip Flops, Counters, Registers)
	BSc. Telecommunications Engineering		
	BSc. Computer Engineering		
II	BSc. Computer Engineering	CMP 1101: Electronics I	CMOS Logic (NAND, NOR, Invert Gates)
		CMP 1202: Electronics II	TTL Logic (NAND, NOR, Invert Gates), Memory Devices (Latches and Flip Flops)
		CMP 2203: Digital Logic	Master-Slave Devices, Flip Flops, Data Registers, Random Access Memory, Finite State Machines, Programmable Logic Devices
III	BSc. Electrical Engineering	ELE 3104: Applied Digital Electronics	Multiplexers, Demultiplexers and other MSI Circuits, ADC, DAC, Multivibrators, Counters, Shift Registers, State Machine, Memory Systems and Programmable Logic (PAL, PLA, FPGAs)
	BSc. Electrical Engineering		
	BSc. Computer Engineering		

TABLE II.
NUMBER OF STUDENTS ON THE ELECTRICAL, TELECOMMUNICATION AND COMPUTER ENGINEERING PROGRAMMES [6]

Year	Electrical Engineering			Telecommunications Engineering			Computer Engineering			LINE TOTAL
	I	II	III	I	II	III	I	II	III	
2008/2009	74	73	74	63	78	75	-	-	-	437
2009/2010	97	99	121	94	100	88	104	-	-	703
TOTAL	171	172	195	157	178	163	104	-	-	1140

III. THE LABVIEW DIGITAL LAB

The developed LabVIEW Digital Lab supports selected exercises for students using the LabVIEW arithmetic and comparison module, Boolean and numeric controls/indicators and other programming structures/functions. The exercises are so selected not only to enhance the students learning experience during lectures but also to prepare them for the Laboratory assignments in the MDEi. Concepts including logic gates, binary adders, Digital to Analogue Conversion, data transfer and memory devices are supported by the LabVIEW Digital Lab.

All exercises require a student to construct a VI, customized to illustrate a concept under investigation. It is assumed that a student working with the virtual instruments has no prior knowledge of LabVIEW and thus suitable user manuals are developed and provided.

Application of NAND Gates to realize other logic gates is a typical assignment, as shown in Fig. 1. Students are expected to construct the virtual instruments and identify which Logic Gates are realized from the different NAND gate circuits. Alternatively students should be able to construct suitable NAND gate circuits to realize the same logic. Fig. 4 illustrates the virtual instruments

for the various logic gates, which the students are supposed to construct and thereafter analyse truth tables.

In the binary half adder (Fig. 3) and the full adder (Fig. 4), students are expected to derive the respective truth tables and explain why the gates so chosen are used. Sequential Logic circuit exercises involve D latches, as a precursor to shift registers as shown in Fig. 5. After constructing the virtual instrument, students are required use the time delay function in controlling the virtual instrument and monitoring the output state at pre-defined time intervals. In so doing, students appreciate the concepts underlying construction of memory devices.

IV. THE NI MULTISIM DIGITAL LAB

Students use NI Multisim in Digital Electronics circuit simulations. Transistor-Transistor Logic (TTL), Complementary Metal Oxide Semiconductor (CMOS) Logic, memory elements and micro controller units, components commonly used in an electronics Laboratory are supported by the NI Multisim simulation platform. Students are expected to explore the added functionality of simulating NI ELVIS II™ instruments. In this mode, the Digital Reader and Digital Writer are utilized to input and output logic values in the circuit under investigation. Other available instruments that students use are the logic converter and the logic analyzer. The logic converter is used to derive the truth table or Boolean logic implemented by a digital circuit constructed in NI Multisim. It is also used for analyzing a truth table or Boolean expression and producing a corresponding logic circuit. The logic analyzer is used for fast data acquisition of logic states and advanced timing analysis of digital circuits. These instruments are useful for analysis of both combinational and sequential logic circuits.

A combinational Logic Laboratory using the Digital Reader and Digital Writer is shown in Fig. 6. A student is expected to apply different logic combinations on the three digital lines at the input terminals and obtain the corresponding digital output. The Digital Reader and Digital Writer utilize light emitting diodes, which represent logic HIGH and low in the ON and OFF positions respectively. Fig.7 and Fig.8 show typical results on the Digital Writer and Digital Reader for a logic input of 111.

This exercise introduces students to the instruments before attempting the assignments in the MDEi. It also ensures that the circuits being developed are tested before being implemented using the physical hardware. Students use NI Multisim to gain familiarity with all the common

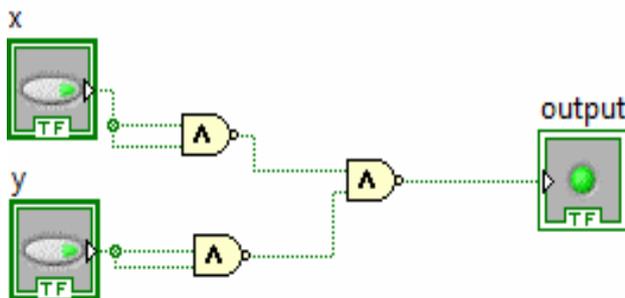


Figure 1. Application of NAND Gates

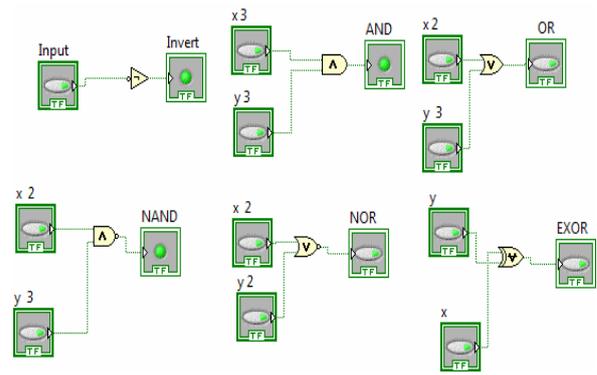


Figure 2. Logic gate virtual instruments

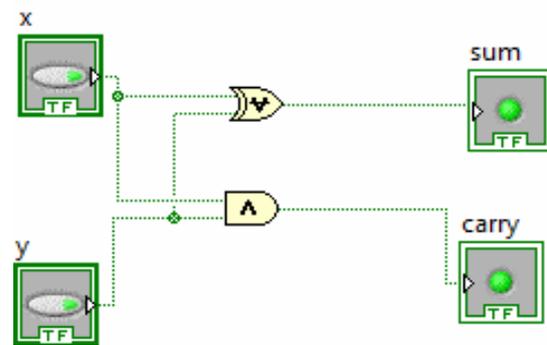


Figure 3. Binary half adder

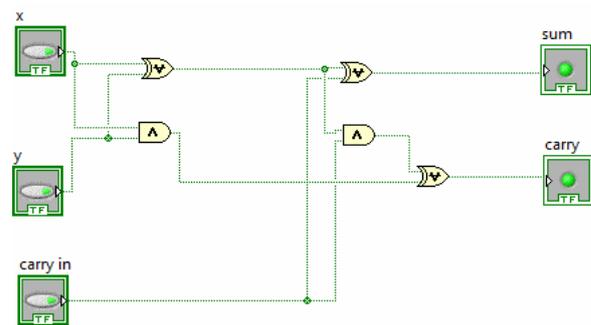


Figure 4. Binary full adder

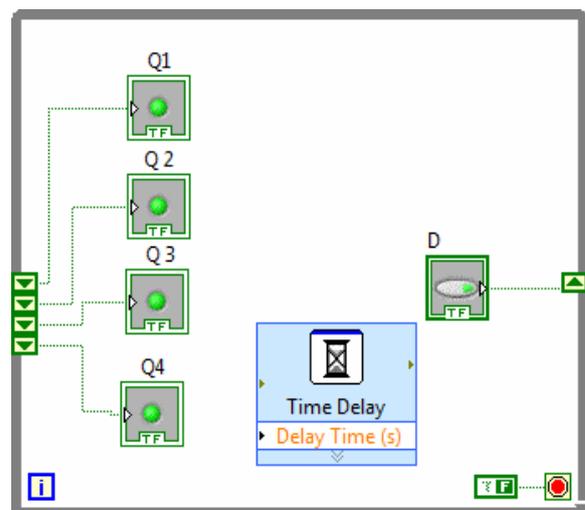


Figure 5. The shift register

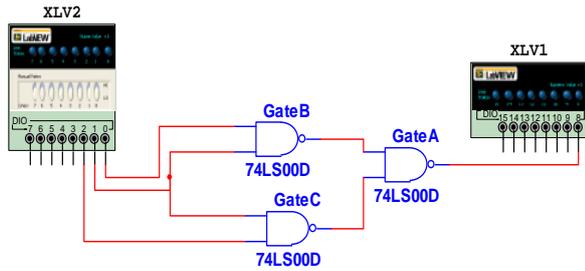


Figure 6. Combinational logic circuit in NI Multisim

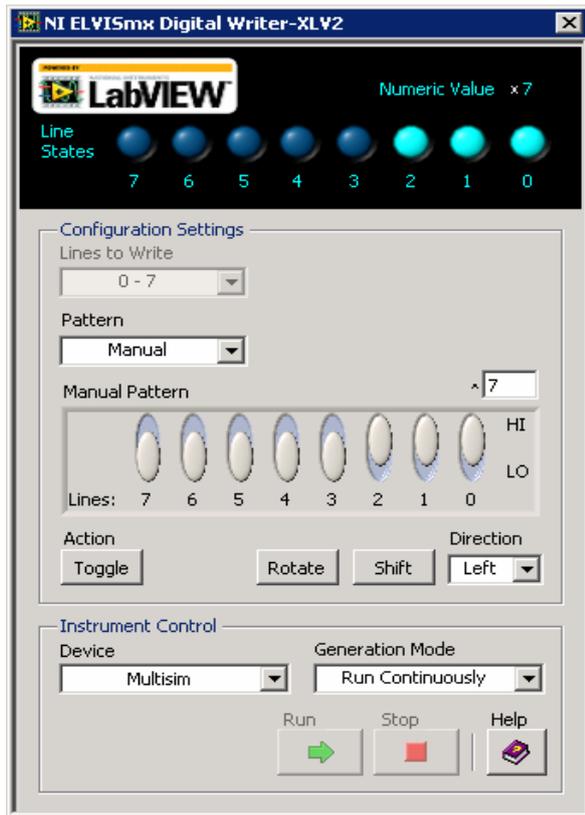


Figure 7. Logic input of 111 on the Digital Writer



Figure 8. Digital Reader output

Digital Electronics components and their properties before using them in the real circuits. Students are also able to access instruments, such as the logic converter, that have no physical counterparts and this adds to the versatility of the environment in circuit design.

V. THE COMBINATIONAL DIGITAL LOGIC iLAB

Having carried out circuit simulation using LabVIEW and NI Multisim, students are ready to perform experiments in the online laboratory. The MDEi supports three major fields: Logic Gate Characterisation, Logic Gate Application and construction of memory elements.

A. Logic Gate Characterization

The objective of this lab is to enable students appreciate the concept of logic gate operation through identification of an unknown gate in a combinational logic circuit. The logic circuit is set up on the NI ELVIS II™ free scale board with a suitable number of inputs and outputs. Students access the user interface to the laboratory through the Service Broker. On launching the user interface, they appropriately configure the Digital Writer and Digital Reader according to the required interface fields as shown in Fig. 9. The number of time steps corresponds to the possible number of input combinations. The experiment is then submitted for execution, success of which yields timing diagrams for the input and output.

From the timing diagrams, a truth table is constructed and an unknown gate identified from the logic being implemented, given the identity of the other gates in the circuit. An output on the user interface is shown in Fig.10 for a circuit with 3 inputs and a single output.

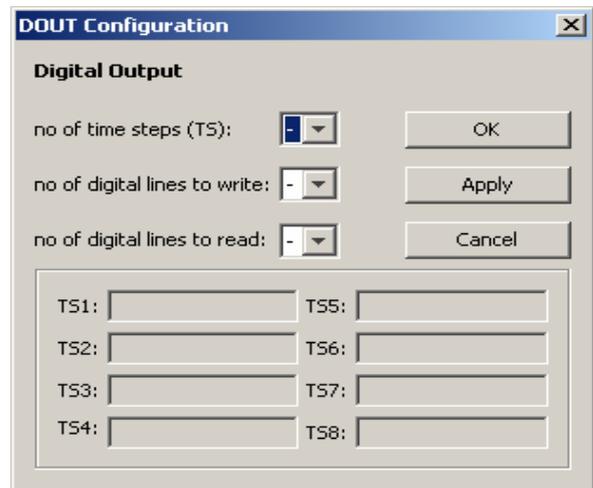


Figure 9. Configuring the Digital Reader and Digital Writer



Figure 10. Results displayed on the graphical user interface

B. Application of NAND Gates

The objective of the lab is to show how TTL NAND gates are used to implement other logic functions. A typical setup utilises a 74LS00 TTL quad two-input NAND gate IC, and a 74LS20 TTL dual four-input NAND gate IC. The experiment is setup on the NI ELVIS II™ breadboard following the schematic in Fig.11. On the user interface, the student selects a suitable number of inputs and obtains the input/output waveforms. They then construct the corresponding truth table. The output logic expression is constructed and using Boolean algebra, it is reduced to the minimized expression. Conclusions are then drawn on how several NAND Gates have been used to implement other gates.

C. Latches as memory devices

This experiment illustrates the concepts underlying latches as the simplest memory elements that can store one bit. A typical experiment is one for the SR latch. The circuit shown in Fig.14 is constructed on the NI ELVIS II™ breadboard using a 74LS02 IC. The student is expected to select a suitable number of inputs and subsequently obtain the input and output waveforms for the possible input combinations after running the experiment. From a truth table, the student should be able to summarise the operation of the circuit and identify the type of latch. Any possible input combinations which give erratic results should be avoided in the experiment. The student makes conclusions about the uniqueness of the 00 and 11 input states, points out weaknesses of the circuit and illustrates how it can be improved.

VI. DEPLOYMENT OF THE MDEI

The MDEi has been used to support curricula in four courses over the past two years as shown in Table III.

TABLE III. MDEI USER STATISTICS

Year	Programme	Year	Course	Number of Students
2008/2009	Bsc. Electrical Engineering	I	Introduction to Digital Electronics	151
	Bsc. Telecommunication Engineering			
2009/2010	Bsc. Electrical Engineering	I	Introduction to Digital Electronics	191
	Bsc. Telecommunications Engineering			
	Bsc. Computer Engineering	I	Electronics I Electronics II	104
TOTAL				446

VII. CONCLUSION

This paper has presented a two pronged approach to teaching digital electronics concepts using virtual and remote Laboratories. The labs as detailed in sections III, IV and V have been availed to students and researchers at the Faculty of Technology, Makerere University in a bid to provide a relevant laboratory experience, albeit not being in physical contact with experiment hardware.

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The user statistics indicate that the laboratory has provided a flexible and convenient experience to a wide community of students in the Faculty of Technology. The laboratory has also been used by undergraduate final year students in research projects, to test and debug digital circuits before hardware implementation.

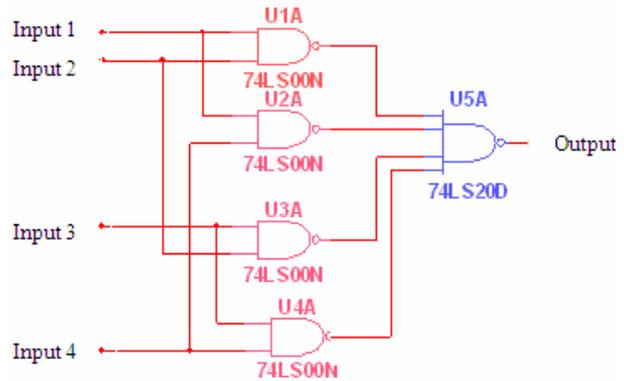


Figure 11. A typical schematic for NAND gate application

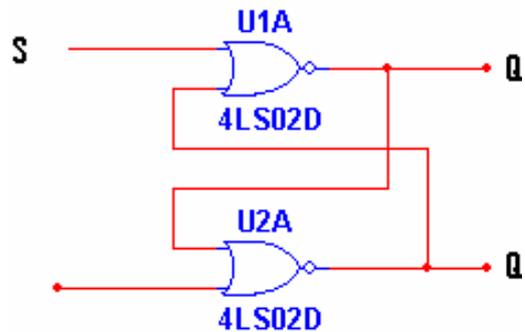


Figure 12. SR latch

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