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Dr. Tomovic received BS in Mechanical Engineering from University of Belgrade, MS in Mechanical Engineering from MIT, and PhD in Mechanical Engineering from University of Michigan. Dr. Tomovic is currently serving as Chair of Engineering Technology Department, F. Batten College of Engineering and Technology, Old Dominion University, Norfolk, VA. Prior to joining ODU Dr. Tomovic had seventeen years of teaching and applied research experience at Purdue University, with emphasis on manufacturing and product development. While at Purdue University, Dr. Tomovic held chaired position - W. C. Furnas Professor of Enterprise Excellence, he was also University Faculty Scholar, Director of Digital Enterprise Center, and Special Assistant to Dean for Advanced Manufacturing. He has co-authored one textbook on materials and manufacturing processes that has been adopted by over 50 national and international institutions of higher education. In addition, he has authored or co-authored over 90 papers in journals and conference proceedings, focused on applied research related to design and manufacturability issues, as well as issues related to mechanical engineering technology education. Dr. Tomovic made over 20 invited presentations nationally and internationally on the issues of design optimization and manufacturability. He has co-authored four patents, and over 100 technical reports on practical industrial problems related to product design and manufacturing process improvements. Dr. Tomovic is also serving as Honorary Visiting Professor at Beihang University, Beijing, China.

A Virtual Laboratory Development Focusing on Hands-on Wiring Experience for Distance Education Students in Programmable Logic Controller (PLC)

Abstract

When teaching PLC classes in the distance-education (DE) program, one of the main problems is to provide hands-on experience to students. This is because students can only use design software to complete their homework and lab problems without being able to touch PLCs or wire ladder logic diagrams. In this paper, the authors develop a virtual laboratory to help DE students gain hands-on wiring experience in the automation control classes. The development significantly shortens the gap on the issue of hands-on experience between on-campus students and DE students. To increase the performance of safety and effectiveness, on-campus students can also take the advantage of using the software before implementing their laboratory works or submitting homework problems.

1. Introduction

As DE programs become more prevalent, and as the undergraduate engineering programs are being developed in a distance-learning format, questions about laboratories and their role in engineering education will become increasingly important[1,2]. Several approaches which were presented to resolve the issue are listed as following:

a. Design Software[3,4]
  While DE students can have design experience and simulate the results by using the design software, they don't have the same laboratory experience as on-campus students.

b. Partnership with Local Institutions and/or with Industry Partners[5,6]
  DE students can gain the laboratory experience through internship programs. Depending on the locations and characteristics of the institutions, students may not be able to find the same hands-on experiences as on-campus students.

c. Intensive Weekend Laboratory[7]
  DE students are asked to come to the campus during the weekends to perform intensive laboratory works. However, the traveling cost and scheduling will become a big issue for DE students.

d. CD –ROM based lab[8]
  The CD-ROM shows the instructor setting up the equipment in accordance with diagrams provided to the students. The equipment is then operated by the instructor and a student assistant in a step-by-step fashion with the camera zooming in on each instrument reading and at other appropriate times. The student watching the video records the data in the same fashion as if he or she were the recording member at a group performing the test in the actual

laboratory. The student then analyzes the data, prepares performance calculations and curves and submits comprehensive reports to the instructor. In this approach, DE students can only watch the operations.

e. Mobile labs[9]

Since the Mobile Studio provides a portable lab facility, students can apply the tools they use in the classroom in their personal projects. The most obvious examples involve tinkering with cars and robotics. However, similar to the intensive laboratory, the traveling cost, locations, sizes of the equipment, and scheduling will become a big issue for the program and DE students.

To overcome the issues mentioned in the above approaches, the paper presents the development of a virtual laboratory which performs exactly the same as the real equipment. As the images of the equipment are very similar to (or look exactly the same as) the real equipment, students will be able to gain the same hands on experience as on-campus students. The virtual laboratory is developed by using the following steps: (1) description of the real equipment, (2) virtual device development, and (3) functioning tests of the virtual devices

2. Description of the Real Equipment

Figure 1 shows three main components of the real equipment: (1) power supply box, (2) manual switch box, and (3) electrical relay switch box. The equipment is used to provide students hands-on experience in wiring the relay schematic ladder diagrams. Figure 2 shows the system when it is powered on. A brief description of each component is listed as following:

2.1 Power Supply Box

The manual push button must be clicked to activate the power as indicated on the displayed LED.
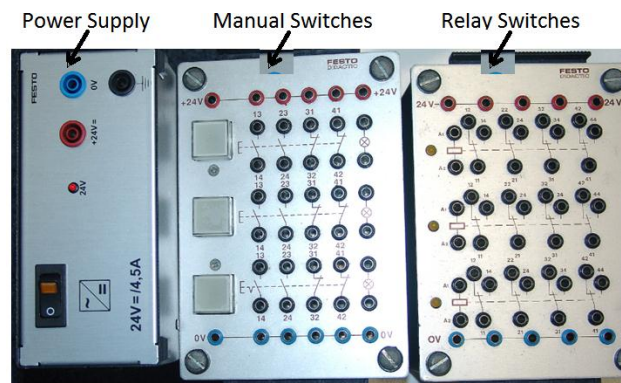

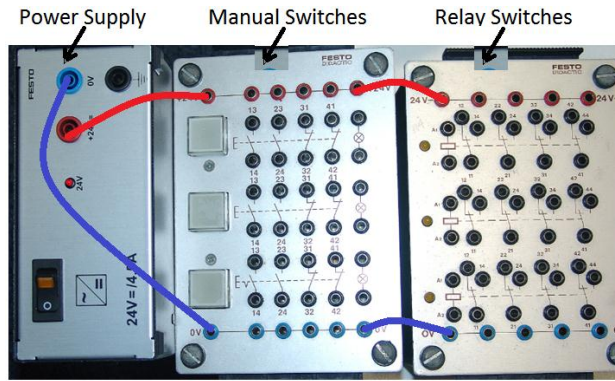**Figure 1:** Pictures of the Three Main Components

Figure 2: The System Is Powered on

2.2 Manual Switch Box

There are three manual push buttons on this box with each button controls four connections: two normally open[10] (NO) and two normally closed (NC)[10] contacts. Table 1 shows the power status of each connection when the push button is activated or deactivated.

Table 1: Connections and Manual Push Button

Connections	Status When Push Button Is Activated	Power Status When Push Button Is Deactivated
13 & 14 (NO)	ON	OFF
23 & 24 (NO)	ON	OFF
31 & 32 (NC)	OFF	ON
41 & 42 (NC)	OFF	ON

2.3. Relay Switch Box

Similar to the manual switch box, each relay controls four pairs of NO and NC connections. Figure 3 shows that the first relay is activated. Table 2 shows the power status of each connection when the relay switch is activated or deactivated.
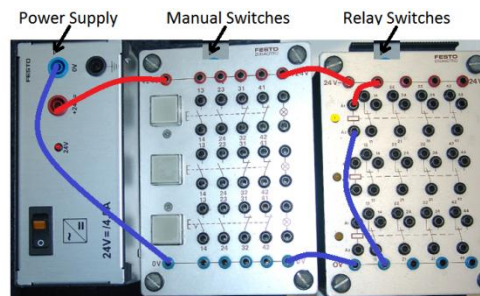

Figure 3: A Relay Switch Is Activated

Table 2: Connections and Electrical Relay

Connections	Electrical Relay Power Status When Activated	Electrical Relay Power Status When Deactivated
12 & 11(NC)	OFF	ON
22 & 21(NC)	OFF	ON
32 & 31(NC)	OFF	ON
42 & 41(NC)	OFF	ON
14 & 11(NO)	ON	OFF
24 & 21(NO)	ON	OFF
34 & 31(NO)	ON	OFF
43 & 41(NO)	ON	OFF

3. Virtual Device Development

Main goal in this approach is to develop a virtual laboratory so that the equipment images in Figure 3 can perform the same function as the real equipment. Programming scheme for the devices is not included in this paper. Figure 4 shows the developed computer model. Images of the three main components are created in three dimensional using a CAD system. In this figure, power supply, manual switch box, and relay switch box are located at the top, bottom right, and bottom left respectively. In addition, six auxiliary icons are also created in this development:

a. Cable Color Selection
    Students will be able to select colors for the wiring cables used in their laboratory works. For example, they may choose red color for the cables connected from the +24V- Volt power source and blue for the cables connected to the 0-V power source.

b. File Save
    Each student can save his/her project in a file which can be used to submit his/her work to the instructor and/or stop his/her unfinished work whenever he/she wants.

c. File Open
    The instructor can use this icon to open a file sent from a student for grading purpose, or a student can continue his/her unfinished work.

d. Volume Control
    Students can use this function to control the voice volume for a warning signal, such as a short circuit occurs.

e. Help
    This icon provides several programming examples for new users.

f. System Close
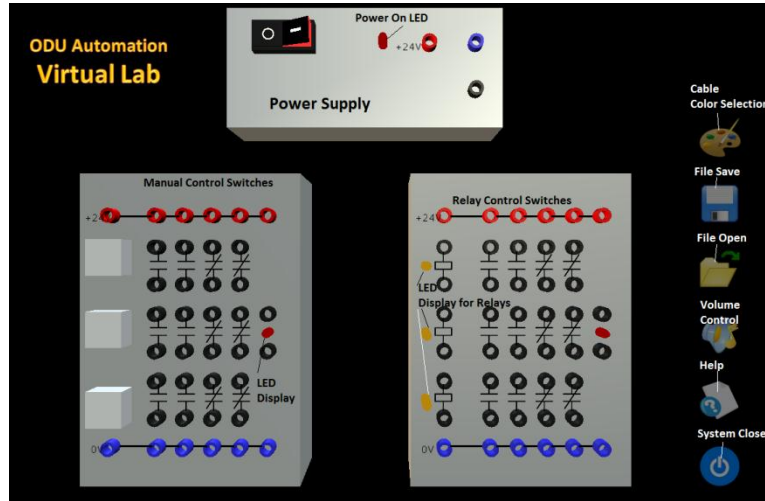   Students can exit the system by clicking on this icon.

Figure 4: Detailed Function for Each Symbol or Connection

4. Functioning Tests of the Virtual Devices
Tests are performed for manual switches first and then relay switches.

4.1. Manual Switches

Figures 5 to 10 show the ladder diagrams and wiring operations for six basic logic gates with all expected results received.
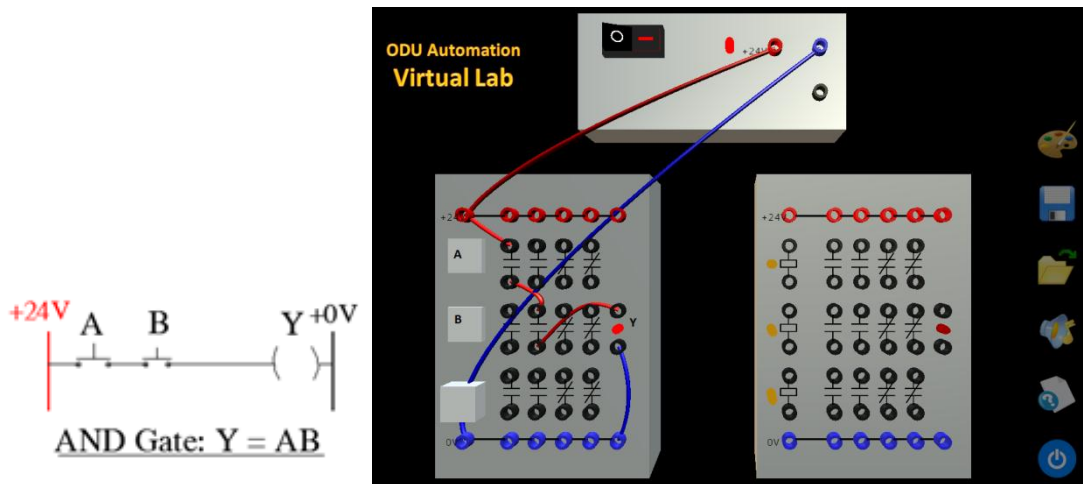

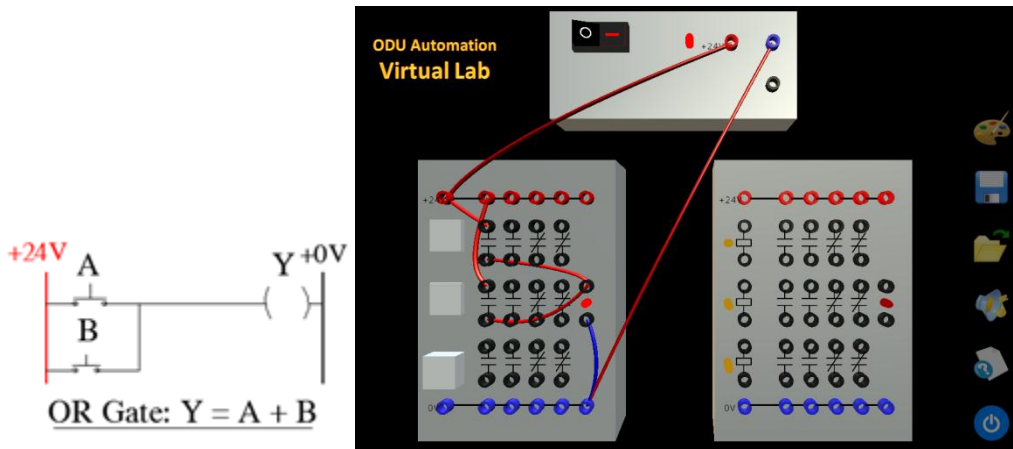**Figure 5**: AND Ladder Diagram and Wiring
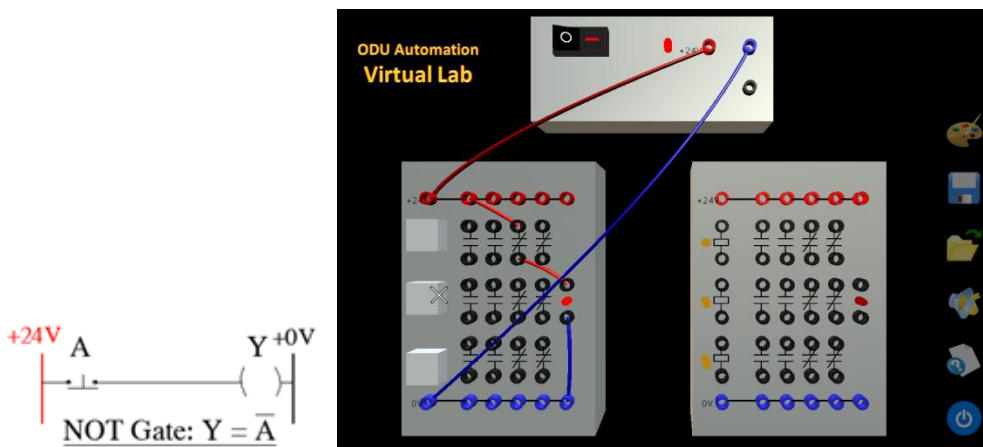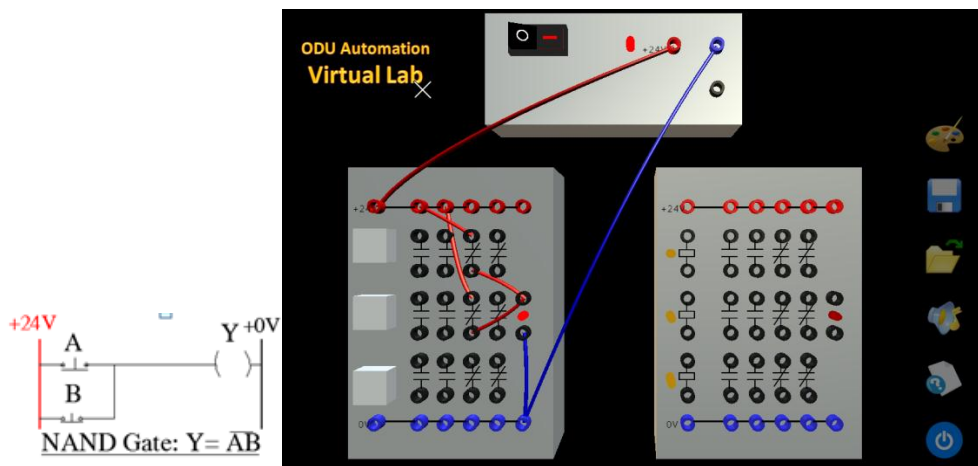
Figure 6: OR ladder Diagram and Wiring

OR Gate: Y = A + B

Figure 7: NOT Ladder Diagram and Wiring

NOT Gate: $Y = \overline{A}$

Figure 8: NAND Ladder Diagram and Wiring

NAND Gate: $Y = \overline{AB}$
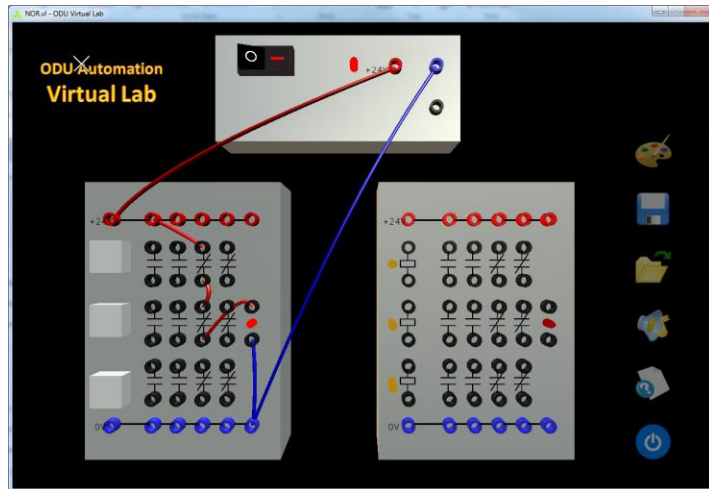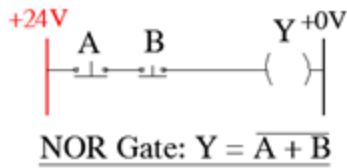
Figure 9: NOR Ladder Diagram and Wiring

+24V A B Y +0V

NOR Gate: $Y = \overline{A + B}$
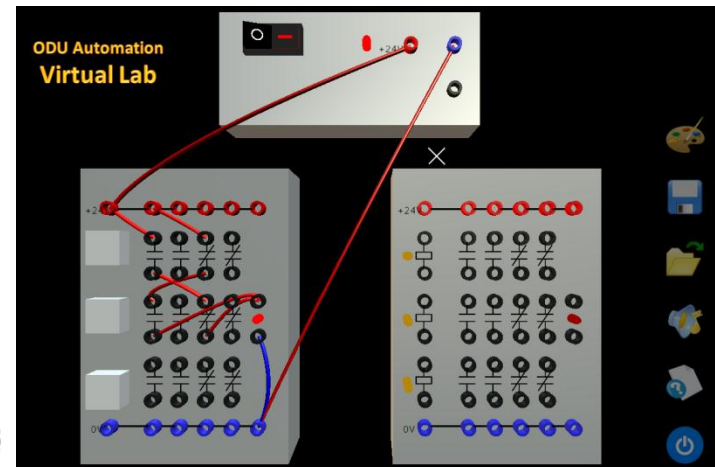
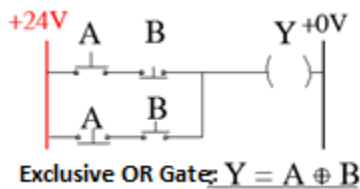**Figure 10**: Exclusive OR Ladder Diagram and Wiring

+24V A B Y +0V

A B

Exclusive OR Gate: $Y = A \oplus B$

4.2. Relay Switches

Numerous relay-control-related ladder programs were tested with all expected results received. Figure 11 is a simple program for NO and NC contacts. When push button A is not pressed, L1 should be off and L2 should be on as shown in the figure. Figure 13 shows that both contact relays Y and L1 are on and the display LED L2 is off when A is pressed.
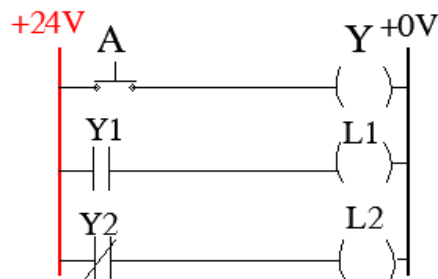
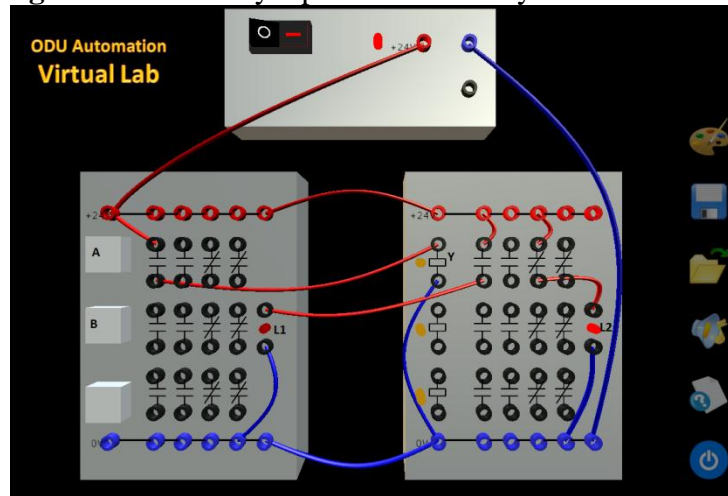**Figure 11**: Normally Open and Normally Closed Contacts

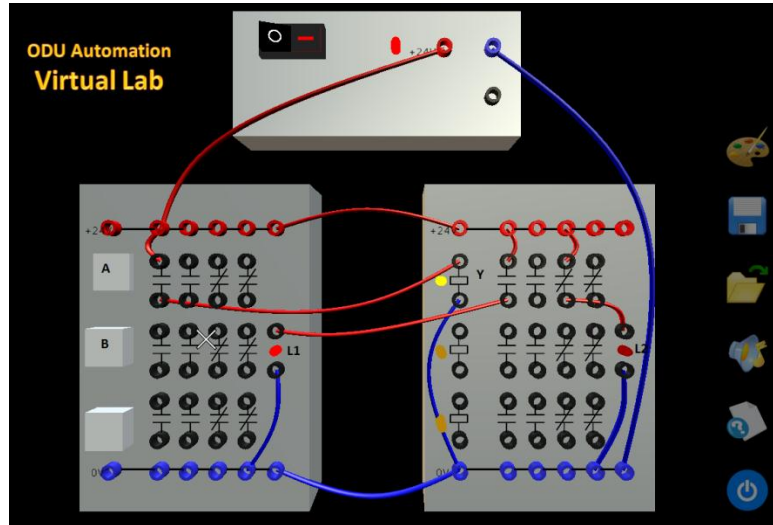**Figure 12**: L1 Is Off and L2 Is On when Push Button A Is Not Pressed
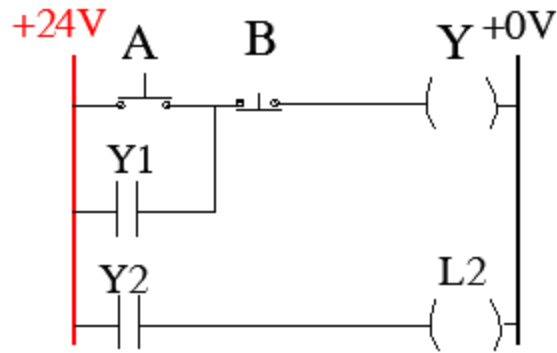

Figure 13: L1 Is On and L2 Is Off when Push Button A Is Pressed

Figure 14 shows a memory-seal ladder diagram. In this case, when push button A is pressed and released immediately, Y is on and stays on until another push button B is pressed. Figure 15 shows the expected result in the wiring. The system resets when B is pressed.

$$Y = A\overline{B} + Y$$

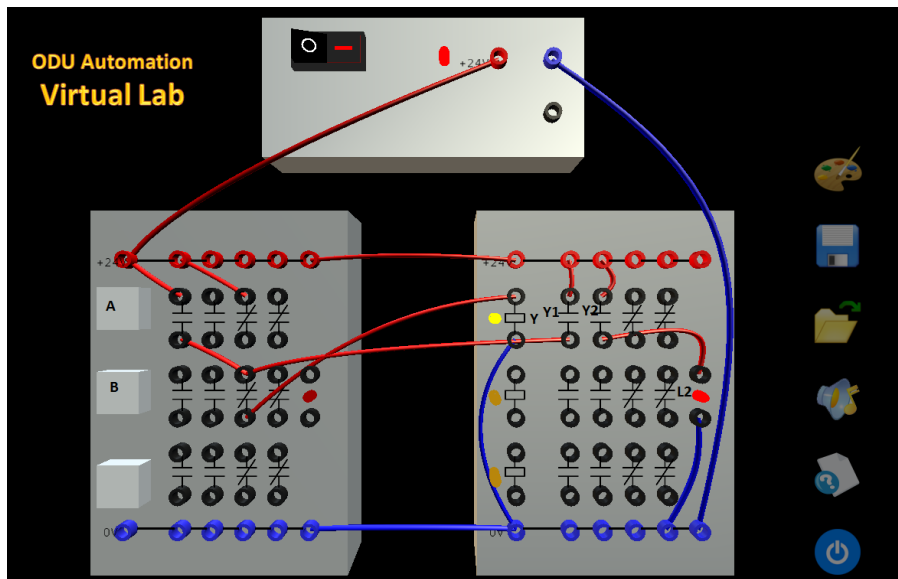**Figure 14:** Memory-Seal Ladder Diagram

Figure 15: Y and L2 Are On When A Is Pressed and Released Immediately

4.3. Easy Access for Students

As the virtual laboratory is placed on the website, students can access the software through PCs, tablets, and iPhones, etc. Figure 16 shows that the software can run in a Windows 8 tablet.
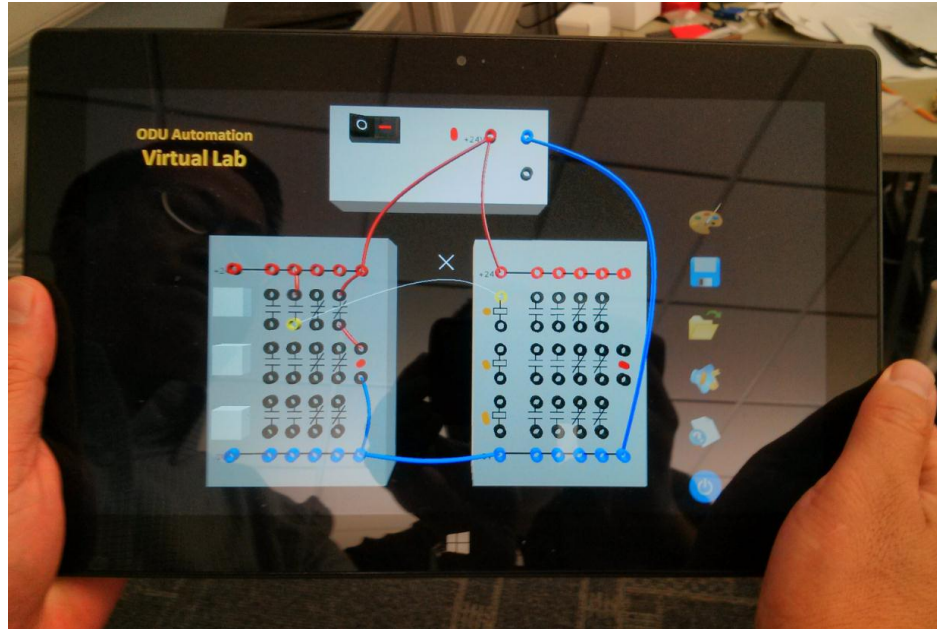
Figure 16: Run the Software through a Windows 8 Tablet

5. Classroom Tests

The hands-on software was firstly tested in an on-campus class as there was no distance-education class scheduled at that time. Table 3 shows the results of survey questions.

Table 3: Results for Survey Questions
5: strongly agree; 4: moderately agree; 3: agree; 2: partially agree; 1: disagree completely

Survey Questions	Results
1. The software helps me gain the knowledge in logic-gate wiring.	4.41
2. The software saves me time to learn logic-gate wiring and improves my actual wiring speed significantly.	3.89
3. The software functions almost exactly the same as the real equipment.	4.00
4. The software is user friendly.	3.76
5. I would highly recommend the software when no real equipment is available.	4.35
6. It would be helpful to have a version of the software running on tablet computers, such as iPad, Surface, etc.	4.18
7. I would like to have similar software for other labs.	4.35
8. I hope the software can handle more complex logic and contain more instruments.	4.06
9. I hope the software can run on Apple computers.	4.00

From this survey, encouraging results were received in survey questions 5 and 7. Since the software was not available until the third week after the semester started, low scores were received in survey questions 2 and 4. As there were only seventeen students taking the survey, the instructor will keep testing the software the coming semesters when DE classes will be offered.

6. Summary

As on-campus students can access the real equipment for their laboratory works, they can easily identify the differences between the real and the developed virtual-laboratory devices. The tested results through an on-campus class are very encouraging. In the teaching-evaluation survey of this class, students particularly wrote the comments, such as "Hands on computer software for completing class work" and "The labs were helpful". Students also highly recommend the software when no real equipment is available. When combined with the approach of CD-ROM Labs[8], the virtual-laboratory software can significantly reduce the hands-on issues for distance-education programs.

Acknowledgement

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