Design and Development of a Low Cost Programmable Logic Controller Workbench for Education Purposes

A. F. Kheiralla
Faculty of Engineering, University of Blue Nile, P.O. Box 143, Elrosseris, Sudan
e-mail: kheiralla65@yahoo.com , saona4@maktoob.com

Osama Siddig [1], Ahmed A. Elhaj Mokhtar [2], Montasir Esameldeen [3], Osama Abdalla [4]

Abstract - **As the response to the feedback from academic and industry, the department of Agricultural Engineering, Faculty of Engineering and Architecture, University of Khartoum has successfully designed and developed a low cost programmable logic controller (PLC) workbench for educational purposes. The developed bench, hardware consist of PLC (Siemens, STEP7-224XP) unit, 24V/10A DC (CE, DP177.101) power supply, personal computer, USB/PPI multi-master cable, three DIN Rail, ten pieces of 24 VDC relays, thirty jacks, thirty sockets. The selected PLC unit has two communication ports, fourteen inputs and ten outputs discreet plus two inputs and one output analog. Laboratory activities of the PLC workbench includes five developed modules namely replacing relays by PLC, (AND/OR/NOT) functions, latching, timer, and counter as well as packing system prototype. A Ladder diagram under Micro/Win32 software is used to run the workbench. The developed PLC workbench has a facility to be upgraded to include human machine interface (HMI), modem module, and considered as a base for new Agricultural Automation and Robotic Laboratory. The unit total cost is about 1600 US Dollars.**

Index Terms - University of Khartoum, Engineering Education, PLC, Teaching Aid

INTRODUCTION

As a result of rapid advancement of technology, complicated control tasks are accomplished with a highly automated control system. This system may be in the form of programmable logic controller (PLC) and possibly a host computer and accompanied with signal interfacing to the field devices such as operator panel, motors, sensors, switches, solenoid valves and etc... . Capabilities in network communication enable a big scale implementation and process coordination besides providing greater flexibility in realizing distributed control system. Every single component in a control system plays an important role regardless of size.

Generally, PLC can be defined as a digital electronic device that uses a programmable memory to store instructions and to implement functions such as logic sequencing, timing, counting and arithmetic in order to control machine and processes. The term logic is used because the programming is primarily concerned with implementing logic and switching operations.

PLCs are widely used in agricultural production and processing. Example applications include food processing [1], building environmental control [2], grain drying [3], animal production [4], and aquaculture production [5]. This has created a need for teaching instrumentation and PLC in undergraduate classroom. Schumacher *et al.* [6] illustrated in his paper titled Agricultural Systems Management in the New Millennium that respondents perceived electricity and electronics of highest importance in this millennium. From some conclusions of his research, the new technology had impacted the curriculum of agricultural engineering programs; some of mechanization concepts that were once taught have been de-emphasized while business and high tech areas have been strengthened, the subject matter area of electricity and electronics will make up much of the core subject matter for at least the next five years.

Given the prevalence of PLCs in the agricultural industry, undergraduate agricultural engineering students should receive hands-on experience with these devices as a component of the instrumentation course. Understanding of control and PLC principles is anticipated to provide more job opportunities and good performances for Agricultural Engineering graduates. This project is meant to supply students with basic information on the functions and configurations of PLCs. Furthermore, the significant feedback received from employers in industry stated that the department's graduates need better training in new technologies such as computers, instrumentation, GIS, GPS, vehicle tracking system...etc. As a response to that feedback, the Agricultural Engineering Department, Faculty of Engineering and Architecture, University of Khartoum has initiated many projects to update its instrumentation laboratory. Before starting the proposed project, the

[1] Osama Sidig, Department of PLC, Sayga Flour Mills, Khartoum North, Sudan, e-mail: osama.siddig@dalgroup.com
[2] Ahmed A. Elhaj Mokhtar, Faculty of Engineering and Architecture, University of Khartoum, P.O. Box 321, Khartoum, Sudan
[3] Montasir Esameldeen, Faculty of Engineering and Architecture, University of Khartoum, P.O. Box 321, Khartoum, Sudan, e-mail: sona4@maktoob.com
[4] Ahmed A. Elhaj Mokhtar, Faculty of Engineering and Architecture, University of Khartoum, P.O. Box 321, Khartoum, Sudan

department did not offer an undergraduate laboratory course dedicated to PLC in its instrumentation course. Therefore, department staff needed to create a new laboratory in instrumentation includes PLC that is most relevant to the agriculture and food industries.

The overall objective of this study is to design and develop a low-cost PLC workbench for education purposes to be used in instrumentation course in agricultural engineering department. The work involves:

1. To design and develop laboratory modules of some ladder logic functions.
2. To design and develop an automated packing system prototype.

MATERIALS AND METHODS

The following criteria were established to guide the development of the workbench:

- The workbench must be safe for students to use.
- The workbench must allow for programming the PLC via computer.
- The workbench must allow programming the PLC using ladder logic.
- The workbench must include typical PLC functions such as logic, counting, timing, latching, pulse, etc.
- The workbench must accept a minimum of four digital (on-off; high-low) and two analog PLC inputs.
- The workbench must allow two or more outputs, and one analog or more outputs.
- The workbench enables the students to possess the sense of control engineering, so as to use that in agricultural engineering applications.
- To help students to be able to translate engineering ideas from theoretical description to practical tutorials.
- To help student to be able to modify programs (ladder logic), detecting the error and troubleshooting it correctly.
- To help students to be able to analyze the process in terms of time and cost via alternative programming techniques.

Description of the Workbench

The purpose of the PLC workbench is to provide experience with PLC and related equipment commonly found in industry. The workbench can be configured into different process plants simply by making different quick-connect wire connections with input and output. The equipment installed on the PLC workbench includes: a personal computer (PC) and monitor, PLC unit, program software, power supply, relay, power source. The workbench was made from PMF with overall dimensions of 1460mm length, 800mm width, and 1200mm height.

PLC Unit Selection and Programming Device

Design of the PLC workbench began with the selection of the PLC unit. After evaluating various manufacturers and models, the Siemens manufacturer brand was selected as reason of prevalence use in Sudan. In this project the CPU 224XP series S7200 PLC was selected because it's ease of use and software available as a no-cost download. The DC power supply, DC input and DC output were selected because its safety for use. A personal computer (PC), with Micro/WIN32 software was used as a programming device with the selected PLC. The PLC was connected to computer by using a USB/PPI Multi-master cable.

DEVELOPMENT OF PLC WORKBENCH

The PLC workbench was successfully designed, developed and tested at Agricultural Engineering Department Faculty of Engineering for educational purposes as a response to feed back from industry. The developed workbench consisted of PLC (Siemens, Model STEP7-224XP) powered by 24V/10A DC (CE, Model DP177.101) power supply connected to Personal Computer by USB/PPI Multi-Master cable, three DIN Rail, ten pieces of 24 VDC (Weidmuller, Model PRZ24VDCLD-1CO) relays, thirty jacks, thirty sockets, five laboratory modules, automated prototype. The PLC unit comprised two communication ports, fourteen inputs and ten outputs discreet plus two inputs and one output analog. The PLC can be upgraded from expansion Module. The whole developed PLC workbench and associated components was depicted in Figure 1. Specification of the PLC workbench is presented in Tables 1 and 2.

(A) OVERVIEW OF PLC WORKBENCH
(B) CPU STEP7-224XP
(C) USB/PPI MULTI-MASTER CABLE
(D) SOCKETS AND RELAYS
(E) POWER SUPPLY

FIGURE 1
THE WHOLE PLC WORKBENCH

TABLE 1
SPECIFICATIONS OF THE PLC WORKBENCH

No.	Item	Model	Description
1	PLC	CPU Siemens STEP7-224XP	See Table 2
2	Power supply	DP177.101	24V/10A DC
3	Personal Computer	Pentium 4	CPU 2.8 GHZ/ 256 MB of RAM
4	Multi-Master cable	RS 485	USB/PPI
5	relay	PRZ24VDCLD-CO	24 VDC

TABLE 2
SPECIFICATIONS OF THE PLC UNIT

Features		Descriptions
Model		CPU224XP-DC/DC/DC
Physical size (mm)		140 x 80 x 62
Program memory	with run mode edit	12288 bytes
	without run mode edit	16384 bytes
Data memory		10240 bytes
Memory backup		100 hours typical
Local on-board I/O	Digital	14 In/10 Out
	Analog	2 In/1 Out
High-speed counters	Single phase	4 at 30 kHz 2 at 200 kHz
	Two phase	3 at 20 kHz 1 at 100 kHz
Pulse outputs (DC)		2 at 100 kHz
Analog adjustments		2
Real-time clock		Built-in
Communications ports		Two RS485
Floating-point math		Yes
Digital I/O image		size 256 (128 in, 128 out)
Boolean execution speed		0.22 microseconds/instruction
Power Supply		20.4-28.8 VDC

PLC LABORATORY MODULES

After careful consideration of the laboratory modules needs, and a thorough other course of Siemens S7 PLC programming, it was decided that five PLC laboratory modules in ladder logic program will be implemented. The first module replaced relay by PLC, followed by Boolean algebra module, latch module, timer module and last module was counter function. All these modules were executed by using PLC workbench, lamps and switches. The five modules were designed and developed as laboratory activity exercises and test the functionality of the workbench. All developed modules were tested successfully without much problems.

- First module replace relay by PLC give students hands-on experience in the control by relays and how can replace relay by PLC. Figure 2 shows the relay controller module. In this module the first relay on the left is used as normally closed, and will allow current to flow until a voltage is applied to the input A. The second relay is normally open and will not allow current to flow until a voltage is applied to the input B. If current is flowing through the first two relays then current will flow through the coil in the third relay, and close the switch for output C, and that will turn on a light. When replace relay by PLC there were two inputs from push buttons to switch lamp. The inputs activated 24V DC relay coils in the PLC. This will drive an output relay that switches 24V DC that will turn on a light. The module program status is shown in Figure 3.

- Second module shows how ladder programs can be rewritten for combinations of switches to explain some of logic functions (AND, OR, and NOT). For an AND function, a toggle switch X and switch Y were closed (on) and then the lamp turn on. For an OR logic gate situation the toggle switch X or switch Y were being closed (on), and then the lamp turn on. For NOT logic gate situation when the toggle switch X is open (off), and then the lamp turn on. The AND, OR, NOT devices were tested successfully shown in Figure 4.

- The third module was latch. The latch is like sticky switch when bushed it will turn on, but stick in place; it must be pulled to release it and turn it off, If start switch is turned on the lamp is turn on and remained be on when start switch turn off. If stop switch is turned on the lamp is turn off. The module functionality and program status is demonstrated in Figure5.

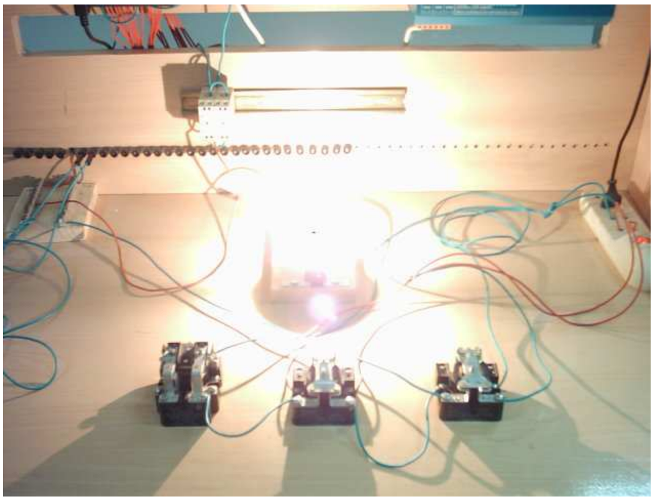


FIGURE 2
THE RELAY CONTROL

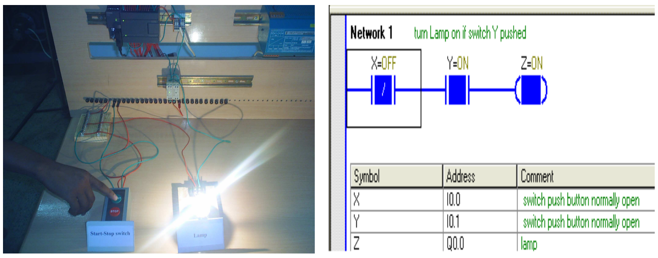
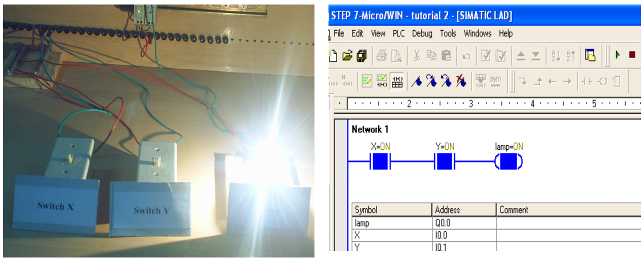


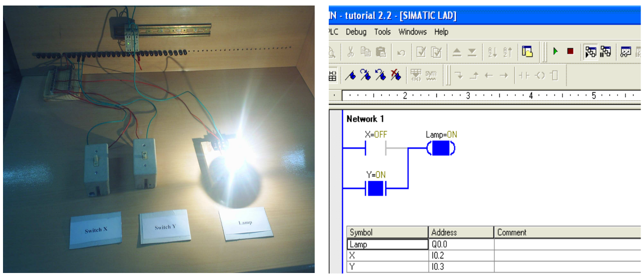
FIGURE 3
THE REPLACING OF RELAYS BY PLC MODULE

- The fourth module was timer represented by flash light. The module was flashing light every second. When the PLC starts, the second timer will be off and the T33 bit will be off, therefore the normally closed input to the first timer will be on. T32 will start timing until it reaches 0.5s, when it is done the second timer will start timing, until it reaches 0.5s. At that point T33 will become true, and the input to the first timer will become false. T32 is then set back to zero, and then T33 is set back to zero. The process starts again from the beginning. In this module the first timer is used to drive the second timer and to turn flash light. This type of arrangement is normally called cascading, and can use more that two timers. The module functionality and program status is demonstrated in Figure 6.

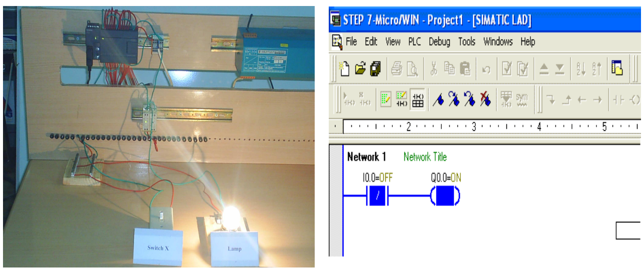
- The last module was counter. The counter up indicator in the lift side turn on after switch push button (X) pushed five times, and counter reset when switch push button (Y) was pushed. And the counter down indicator in the right side turn on after switch push button (M) pushed three times, and counter reset when switch push button (N) was pushed. The module functionality and program status is demonstrated in Figure 7.



AND FUNCTION AND PROGRAM STATUS



OR FUNCTION AND PROGRAM STATUS



NOT FUNCTION AND PROGRAM STATUS
FIGURE 4
(AND/OR/NOT) FUNCTIONS MODULE

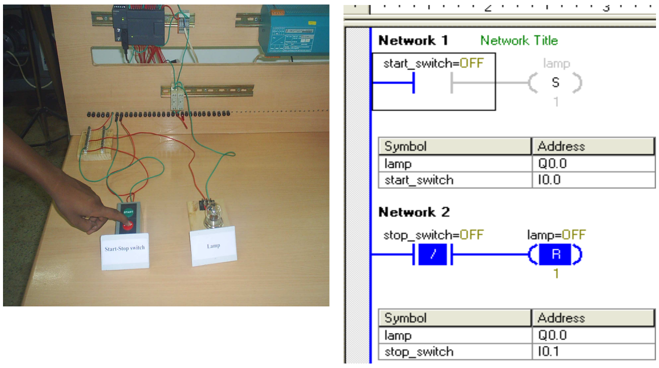


FIGURE 5
THE LATCH MODULE AND PROGRAM STATUS

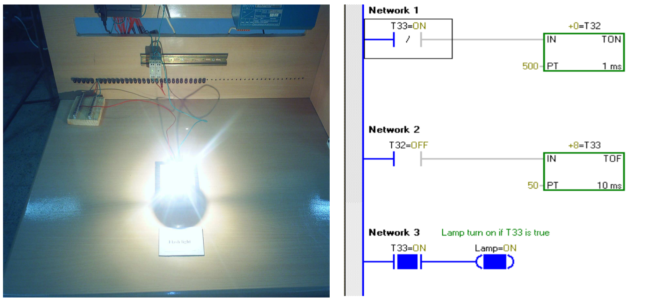
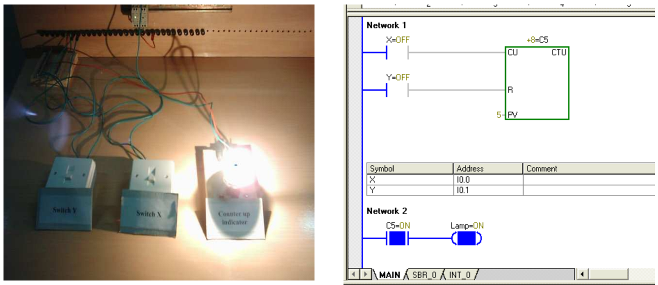
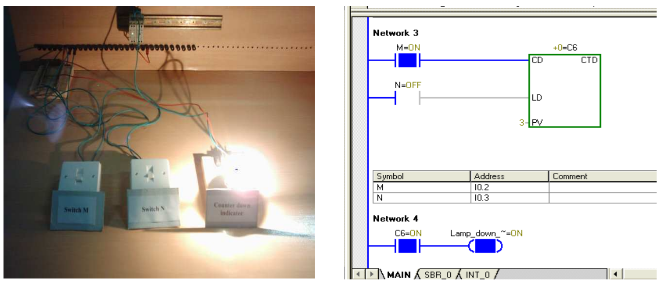


FIGURE 6
THE TIMER MODULE AND PROGRAM STATUS



(A) COUNTER UP AND PROGRAM STATUS



(B) COUNTER DOWN AND PROGRAM STATUS
FIGURE 7
THE COUNTER MODULE

PACKING SYSTEM PROTOTYPE

The prototype was designed to demonstrate the handling operation of the boxes after packing the units inside each one and counting them in precision manner (Figure 8). The numbers of units was already determined by the user program. The handling and packing was performed via belt operated by Maxon, Model HC 236 DC motor. Two light sensors were selected, the first one is Sick, Model WL12 2P130 position sensor and has reflector and it is normally closed that send a signal to the PLC when the box passes through the sensor and the reflector, the second one is Sick, Model 1012 counter sensor and has no reflector and it is normally open that send a signal to the PLC when the unit falls down in front of the sensor from the reservoir. A limit switch is also attached with the system which sends a signal to the PLC when the box catches the end of the packing line. The developed prototype was tested successfully with minor problem. Prototype position sensor was not in the correct place causing fall the units out of the box during demonstration test. Changing the position sensor place solved the problem.

The prototype automation was started by pushing the start button, Indicator (light) will be ON, and the motor will be ON. Then position sensor will be OFF, sequentially, the motor and its indicator will be OFF, after 5 seconds the coil will be ON, and then the gate will be opened by the coil. As a result, the units will fall down and the counter sensor will count up (CTU) until it reaches the preset value in the user program. Then the coil will be OFF, and the gate will be closed so as to prevent the units from falling down. Next, the motor will be ON, and the indicator (light) will be ON. Finally, the limit switch will be ON, and the motor will be OFF, and the indicator (light) will be OFF due to the status of the motor. The prototype ladder logic diagram is shown in Figure 9.

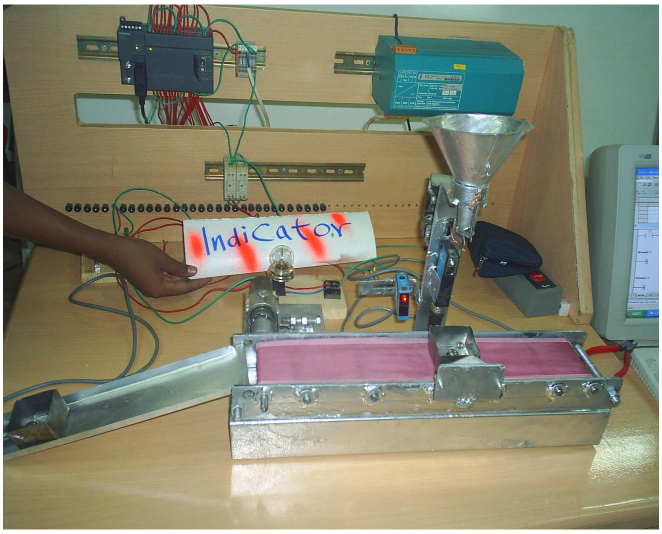


FIGURE 8
OVERVIEW OF PACKING SYSTEM PROTOTYPE

CONCLUSIONS

The following conclusion could be drawn from the obtained results:

- PLC workbenches had been successfully designed and developed for agricultural Engineering Department, instrumentation laboratory. The system included PLC unit (Siemens, STEP7-224XP), 24V DC power supply, personal computer, USB/PPI Multi-Master cable, three

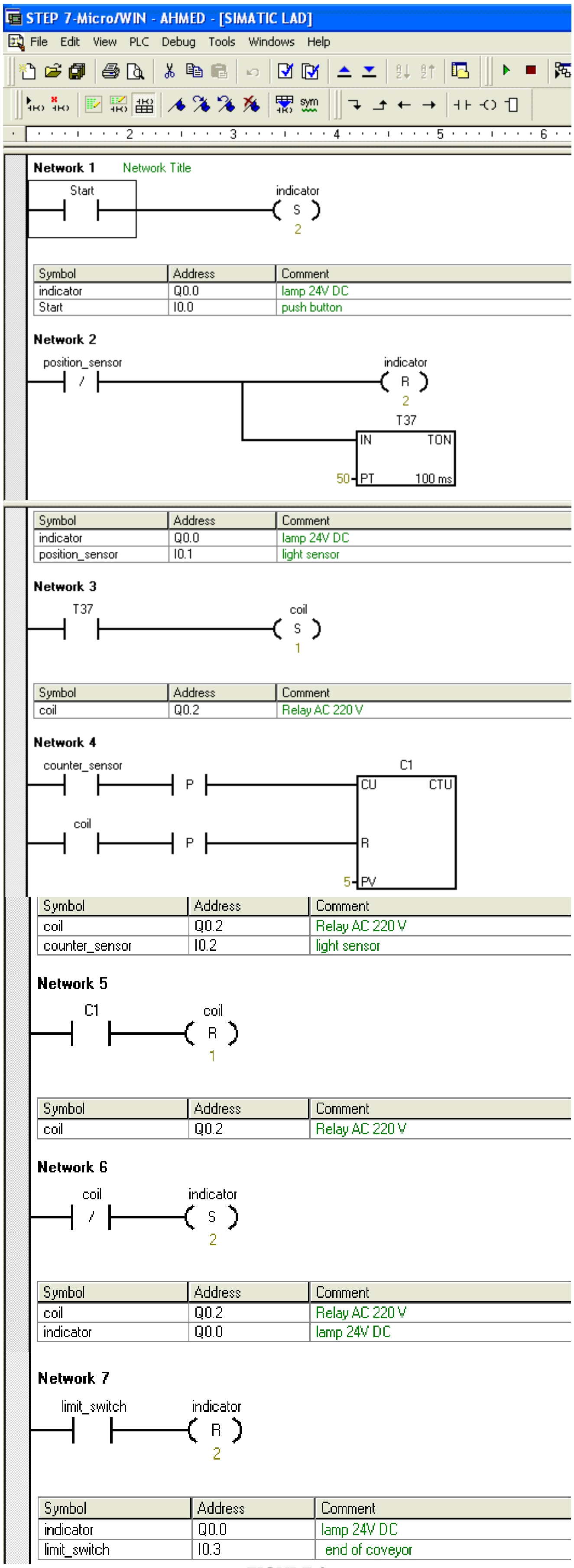


FIGURE 9
THE PROTOTYPE LADDER LOGIC DIAGRAM

- DIN Rail, ten pieces of 24 VDC (Weidmuller, Model PRZ24VDCLD-1CO) relays, thirty jacks, thirty sockets. The total cost of the developed workbench is $1,600 US. While the cost of commercials workbenches in the market at semi specification of this workbench approximately $2250- $3500 US.

- Five laboratory modules of the PLC workbench was successfully designed, developed and tested. These modules included replacing relays by PLC, (AND/OR/NOT) functions, latching, timer, and counter.

- A packing system prototype was also successfully designed, developed and tested. The developed prototype consisted of conveyor, motor, two proximity sensors, reservoir, and coil.

Recommendation and Future Work

The following agenda are to be taken for this study work:

- The workbench should be considered as a base for new Agricultural Automation and Robotic Laboratory.
- The workbench can be supplementary for Instrumentation and Measurement.
- Modem module will allow use internet in control of the workbench.
- Human machine interface (HMI) will make the workbench a useful laboratory teaching principles of SCADA system

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