122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Seattle Making Value for Society
Paper ID #11385

# MAKER: Whack-a-Mole for PLC Programming

**Dr. Sheng-Jen "Tony" Hsieh, Texas A&M University**

Dr. Sheng-Jen ("Tony") Hsieh is Professor in the Dwight Look College of Engineering at Texas A&M University. He holds a joint appointment with the Department of Engineering Technology and the Department of Mechanical Engineering. His research interests include engineering education, cognitive task analysis, automation, robotics and control, intelligent manufacturing system design, and micro/nano manufacturing. He is also the Director of the Rockwell Automation laboratory at Texas A&M University, a state-of-the-art facility for education and research in the areas of automation, control, and automated system integration.

# MAKER: Automated System Design Projects for Undergraduates


## Abstract

The paper describes the design, construction, and programming process for a small-scale automated system to play Whack-a-Mole. This system is one example of several that have been built by undergraduate students learning about automated system design. The system consists of a PLC, power supply, lights, and push buttons and is controlled using a ladder logic program. The system was constructed using FischerTechnik components, so no machining was required. Undergraduate students learn about PLC instructions and how to interface I/O devices with a programmable logic controller (PLC) by designing and building these systems. The Whack-a-Mole module has also been used for K-12 outreach activities. The presentation will include a live demonstration.


## Motivation

Automated systems play a significant role in our daily lives. These systems are the backbone of our national production systems and basic living infrastructure. Exports of automated systems make up a significant portion of our national economy. In November 2014, US export data in the Flexible Manufacturing category was about $1.392 billion [1]. A programmable logic controller (PLC) is used as the central controller for most advanced manufacturing systems. According to Asfahl et al [2], the PLC is among the most ingenious devices ever invented to advance the field of manufacturing automation. Learning how to design and build automated systems is often limited by available equipment and lab time.

One approach to alleviating limitations in equipment availability is to make PLC education virtual. For example, LogixPro (http://www.thelearningpit.com/) employs animated educational simulations of processes, such as traffic control and batch mixing, to show how a ladder diagram relates to an automated process. Students can start and stop the animations, and study the corresponding ladder diagram for certain conditions or cases. In addition, Hsieh has developed an Integrated Virtual Learning System for Programmable Logic Controller (Virtual PLC). This web-based system uses a combination of animations, simulations, intelligent tutoring system technology, and games to teach about programmable logic controllers [3-5]. Both of these systems are good examples of how technology can be used to help students learn simple PLC programming concepts.

However, for learning to write complex programs, there is no good substitute for hands-on experience programming a real PLC. Therefore educating students with integrated knowledge about automated systems is a pressing need. A project-based curriculum seems to help students develop an integrated knowledge of a specific subject [6-9]. In this paper, we share our experience in achieving these goals by adding a model-building project to the curriculum of an existing course.

## Manufacturing Automation and Control Course

The author teaches an undergraduate-level manufacturing automation and control course for Engineering Technology students at a U.S. university. The course covers the following topics: (1) programmable logic controllers and programming, (2) sensor technology, (3) industrial robots and programming, (4) vision system, and (5) industrial interfaces. These are major types of knowledge needed to understand and build automated systems. One challenge is how to deliver integrated knowledge of an automated system. The labs include two exercises to teach students to interface PLC, sensor, and robot. However, to foster a deeper understanding of system integration concepts, a hands-on project experience can be helpful. Therefore students were given the option to complete a semester project in lieu of the final examination. The project requires students to apply techniques/methodologies discussed in classes and labs, such as use of sensors, relays, robot, PLC, and interfacing techniques. Students identify a product and a process to automate and submit progress reports periodically throughout the semester. Each team consists of two people.

Examples of student projects include: (1) use of PLC for injection molding machine control, (2) robotic work cell design for egg packaging, (3) automated system for cutting seat belt retractor sleeves, (4) use of vision system for printed circuit board inspection, (5) automated systems for sorting items by color; and (6) automated systems for entertainment such as Whack-A-Mole Automated System.

## Project System Platform

An automated system typically consists of controller, sensors, actuators, and system structure. Since this class enrolls about 40 students per semester, and teams consist of two members, the use of actual industrial-scale equipment would be tremendously costly. In addition, we wanted system components that could be reconfigured for different purposes and allow several systems to be integrated into a larger system (i.e., scalable). Table 1 lists the components of the platform used for the team projects.

<table>
<tr><td colspan="2">Project System Platform</td><td rowspan="7">Fischertechnik ROBO Starter Set*<br>1. Push buttons<br>2. Sensors<br>3. Motors<br>4. Module components<br>5. Lights<br>*Each Starter Set can build 6 different automated modules</td></tr>
<tr><td>Items</td><td>Cost</td></tr>
<tr><td>1. Allen Bradley Micrologix 1000 PLC</td><td>$200</td></tr>
<tr><td>2. Fischertechnik ROBO Starter Set</td><td>$110</td></tr>
<tr><td>3. 5/12 Volts DC Power Supply</td><td>$15</td></tr>
<tr><td>4. Industrial Relay</td><td>$10</td></tr>
<tr><td>5. PLC software</td><td>$0</td></tr>
</table>

Table 1. Project Platform and Contents

## Whack-a-Mole Automated System

This system is designed to imitate the structure of an amusement park Whack-a-Mole game. Following is a detailed description including physical system, I/O part assignment, system schematic, and ladder logic.

### *Physical System Functionality and Layout*

Figure 1 shows the design of the model. There are five lights in the model; each light represents a Mole. Next to each light is a push button representing a hammer. The program uses a random number generator to randomly turn on a light. A timer is triggered and the user has a few seconds to push the button next to the light. When the button is pushed, the light will turn off and the user will receive a point, which is displayed on a digital counter next to the model. A master timer gives each user a time limit of 30 seconds per game. The highest score is stored in memory and displayed on the digital counter.

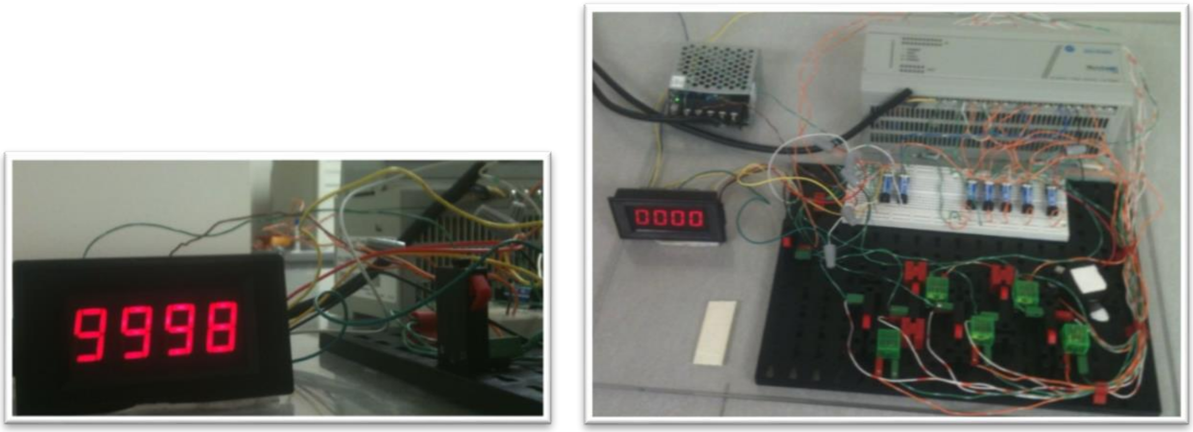


Figure 1. Whack-A-Mole Model.

***I/O Port Assignments***

The system has six inputs and eight outputs. The inputs are the Start button and the five hammers. The outputs include five lights representing five different moles. Another output is used for the buzzer and two others for counting points. The buzzer will sound and the totalizer will increase by one whenever a hammer hits a mole in time. Table 2 shows the I/O address for each I/O.

| Input Address | Input Device Name | Output Address | Output Device Name |
|---|---|---|---|
| I:000/00 | Start button | O:000/01 | Light1 – Mole #1 |
| I:000/01 | PB1 – Hammer #1 | O:000/02 | Light2 – Mole #2 |
| I:000/02 | PB2 – Hammer #2 | O:000/03 | Light3 – Mole #3 |
| I:000/03 | PB3 – Hammer #3 | O:000/04 | Light4 – Mole #4 |
| I:000/04 | PB4 – Hammer #4 | O:000/05 | Light5 – Mole #5 |
| I:000/05 | PB5 – Hammer #5 | O:000/07 | Reset Totalizer Count |
| | | O:000/08 | Buzzer |
| | | O:000/09 | Increase Totalizer Count |

Table 2. I/O Device Addresses

***System Schematic***

The Whack-A-Mole system consists of following components: MicroLogix1000 PLC (1756-L32BWA), 5 Volts DC power supply, buzzer, normally open and spring return push buttons, lights, mechanical relays, and totalizer (point counters). The MicroLogix 1000 inputs require more than 13 VDC for the inputs to be recognized by the processor. Since the PLC itself has an internal 24VDC, an internal power supply was used for all the input and output terminals. Since the push button and buzzer can have 24VDC, they were connected directly to the I/O terminals. On the other hand, the totalizer and lights require a lower voltage. Therefore a 5VDC power supply was used to power them, since these devices need to be controlled by the PLC ladder logic program. A reed relay was used as a bridge device between the output terminals and output devices. Figure 2 shows the schematic for the Whack-A-Mole automated system.

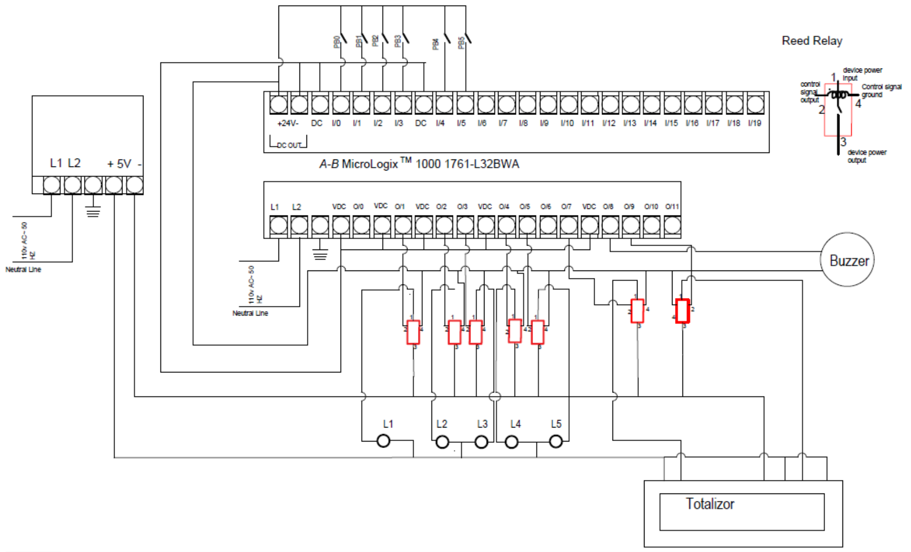


Figure 2. Schematic for Whack-A-Mole automated system.

The MicroLogix 1000 is powered by 110V AC. The power terminals are shown in the bottom left corner. The same 110V AC power source is used for the transformer shown to the left of the schematic to convert the 110 VDC to 5VDC. The top of the schematic shows the wiring for the five normally open and spring return push buttons which mimic the 5 different hammers. The bottom of the schematic shows the wiring of output terminals connected to the replays that drive the output devices (the five lights). The right side of the schematic shows the wiring for the totalizer and buzzer.

***Ladder Logic***

The major program challenge for controlling the Whack-A-Mole system was how to define a random function to flash the lights in different sequences and for different lengths of time. This was accomplished using the SQO function found on Rung 0002. As long as the game is running and the timer for the first light is done, or any light, a new number for the PRESET will occur on the next light ON sequence. A table consisting of 100 numbers, 20, 30, 40…100, will shift position in that table and serves as the new number in the light timing. This rung is the same for each mole (where Mole 1corresponds to Timer 1, Mole 2 to Timer 2, and so on).

Rung 0003 serves to switch the corresponding light off and moves to the next light in the sequence if the scoring push button has been activated.

Rung 0004 serves to decide if the light is on. If the switch has been pressed at the same time and if the switch has not been triggered, then the light will continue to stay on until the Timer for that light has completed its sequence.

Each following Rung has the same format as 0002, 0003, and 0004.

Rung 0017 will activate a Buzzer provided that Rung 0001 is true. That is, a light and its switch are both on and depressed, turning on Timer 6, which indicates a score to the player.

Rung 0018, once Timer 6 is done and if the game Timer 0 is not done, a Counter will be energized. The digital Totalizer will receive a signal and increase by 1.

Rung 0019 triggers the reset for the Totalizer, as well as resetting the game, demonstrated in Rung 0000. Figure 3 show the ladder logic in detail.

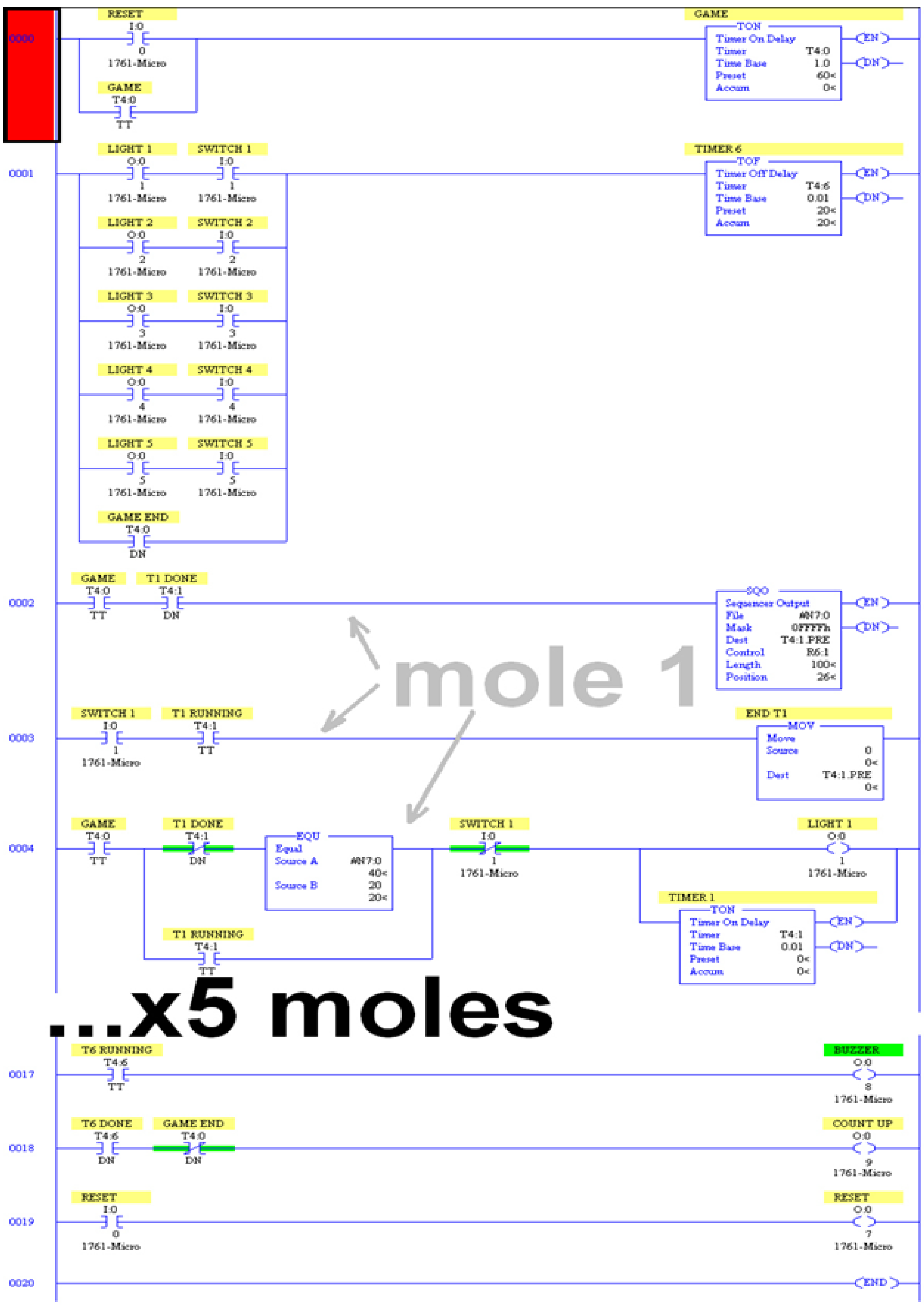


Figure 3. Ladder logic for Whack-A-Mole automated system control.

## Outreach Activities

The automated systems that students build can serve as educational tools to teach the functionality of PLCs and their capabilities. The various projects demonstrate the breadth of what PLCs can automate. The systems are built to fit into a portable, modular box containing a PLC and power supply, so they are portable for travel to various demonstrations and learning events. The Whack-a-Mole model was very popular among younger students attending a recent community outreach activity sponsored by the College of Engineering. Figure 4 shows photos from one of these events.

Figure 4. Educational outreach events.

## Conclusion and Future Directions

In this paper, we described the motive, design, and results related to a project-based activity to enhance undergraduate students' learning about automated system design and integration. The activity provides an excellent opportunity for students to integrate their knowledge of automation building blocks (such as sensor, actuator, relays, switches, push buttons, PLC and interfacing) in real-life problem solving. The experience is challenging, but seems positive and has been well-received by students (some have even brought their parents to see their projects). Future plans include combining multiple models to form a large scale system, creating an on-line documentation system so that teams can blog about their learning experience throughout the project development stage, and making the systems available to be controlled remotely via the web. We also plan to conduct experiments using mobile devices for remote control of systems to evaluate how this affects students' designs and learning.

**Acknowledgements**

This material was supported by grants from the National Science Foundation's Course Curriculum and Laboratory Improvement (CCLI) Program (Award No. 0837634) and Research Experience for Undergraduates (REU) Program (Award No. 1263293). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

**Bibliography**

[1] Online resource available at: http://www.census.gov/foreign-trade/statistics/product/atp/2014/11/atpctry/atpg06.html
[2] Asfahl, C. Ray, (1992), Robotics and Manufacturing Automation, John Wiley & Sons, Inc. New York, NY.
[3] Hsieh, S. and Hsieh, P.Y., "Web-based Modules for Programmable Logic Controller Education," Computer Applications in Engineering Education, 13(4), Dec 2005, pp. 266-279.
[4] Hsieh, S. and Hsieh, P.Y., "An Integrated Virtual Learning System for Programmable Logic Controller," Journal of Engineering Education, 93(2), April, 2004.
[5] Hsieh, S. and Hsieh, P.Y., "Animations and Intelligent Tutoring Systems for Programmable Logic Controller Education," International Journal of Engineering Education, 19(2), 2003.
[6] Hsieh, S., "Reconfigurable and Scalable Automated Systems Projects for Manufacturing Automation and Control Education," ASEE Annual Conference, 2011. [PDF]
[7] Grimm, J.A., et al, "Use of Simple Hands on Design Challenges for Practicing Engineering Design Principles", ASEE Annual Conference 2011. [PDF]
[8] O'Connell, B.P., "Paperbots, An Inexpensive Means for Engineering Education", ASEE Annual Conference, 2013. [PDF]
[9] Williams, S., "Brushless DC Motor Project in an Introduction to Electrical Engineering Course", ASEE Annual Conference 2006. [PDF]