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Design and Evaluation of Sensor Module for Portable Programmable Logic Controller (PLC) Kit for Automated Control Education

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Abstract

Automated control can be found in almost every sector of the economy. Many automated control applications are integrated into daily life, such as traffic lights, automatic doors, elevators, coffeemakers, automated lighting, and copy machines. In all these applications, sensors are used to provide the signals needed to control the machine or process. It is difficult to teach a control language such PLC programming without knowing how sensors work. This paper describes the design and evaluation of a sensor module (consisting of commonly used industrial sensors) and how this module is integrated with a portable PLC kit to make learning about PLCs and sensors convenient and accessible in the classroom and at home. Students have responded positively to portable PLC kit and informal responses from students suggest the needs to develop sensor module as part of portable PLC kit.

Motivation

Automated systems can be found everywhere in daily life. A controller is the heart of an automated system. I/O devices such as sensors and actuators are connected to the controller with a purpose of automating a process.

Programmable logic controllers (PLCs) are mainstream controllers for many existing discrete automated manufacturing systems. Engineers with PLC programming and automated system design skills are highly sought after in the manufacturing industry[1-2]. A better prepared workforce will also increase U.S. economic competitiveness, as exports of advanced manufacturing systems contribute to 15%-20% of U.S. annual exports[3].

There have been a few reports of Maker approaches being used to teach about automated systems but most of these systems use LEGO NXT or Arduino as the controller, not a PLC [4-6]. It is important for future designers to be exposed to industry-level technologies.

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, Hiseh 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 [7-9]. 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.

To become proficient at PLC programming, engineering students need to become familiar with functions and general characteristics of sensors and actuators (I/O devices), to understand how

PLC controllers process programs, to be able to interface I/O devices with a PLC, and to be able to understand the control requirements of an application and write control programs accordingly. Hands-on experience with PLCs, sensors and actuators is needed to develop these skills.

The author is leading an ongoing effort to design and build a low-cost portable PLC kit with quick-disconnect modules for teaching PLC programming and sensors. The kit consists of (1) a controller module, (2) an interchangeable special function module, and (3) a plug and play I/O interface—all integrated in a portable box for easy transport. The controller module contains an industrial programmable logic controller and power supply unit. The special function module is connected to the controller module through a plug and play I/O interface. This paper describes the design, fabrication, and evaluation of the sensor module, which includes commonly used sensors such as RTDs, thermistors, thermocouples, optical sensors (optical interrupter and reflector), and proximity sensors. Figures 1 and 2 show the Portable PLC Kit with the basic and sensor modules.

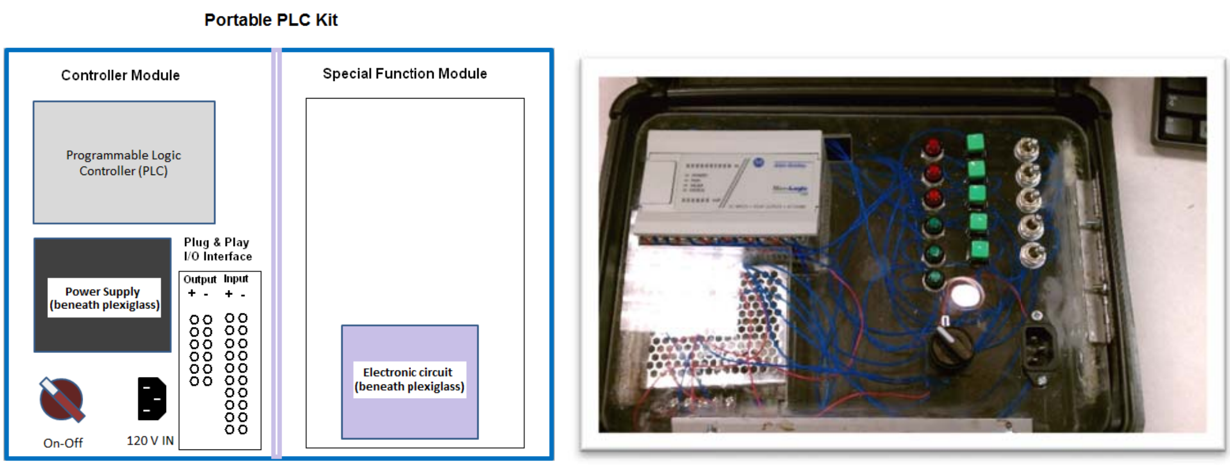

Figure 1. Diagram and Photo of Portable PLC Kit Layout (Basic Module).

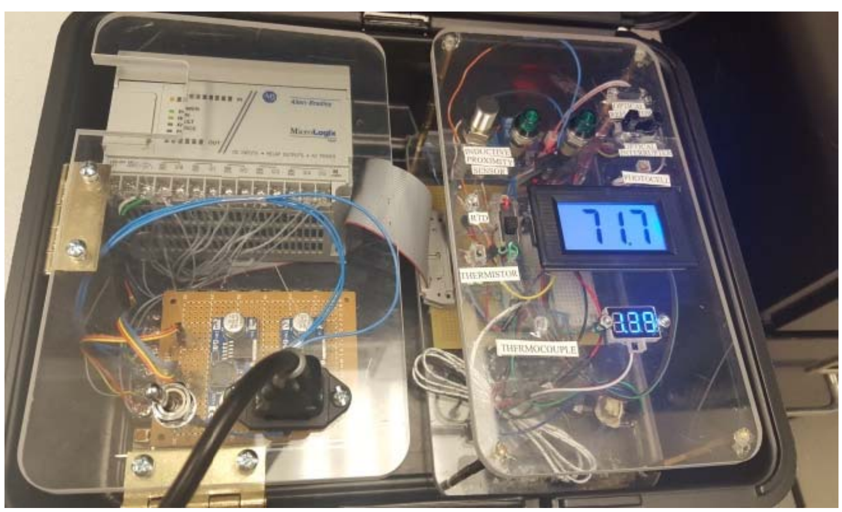

Figure 2. Diagram and Photo of Portable PLC Kit Layout (with Sensor Module).

Sensor Module Design

Block diagram

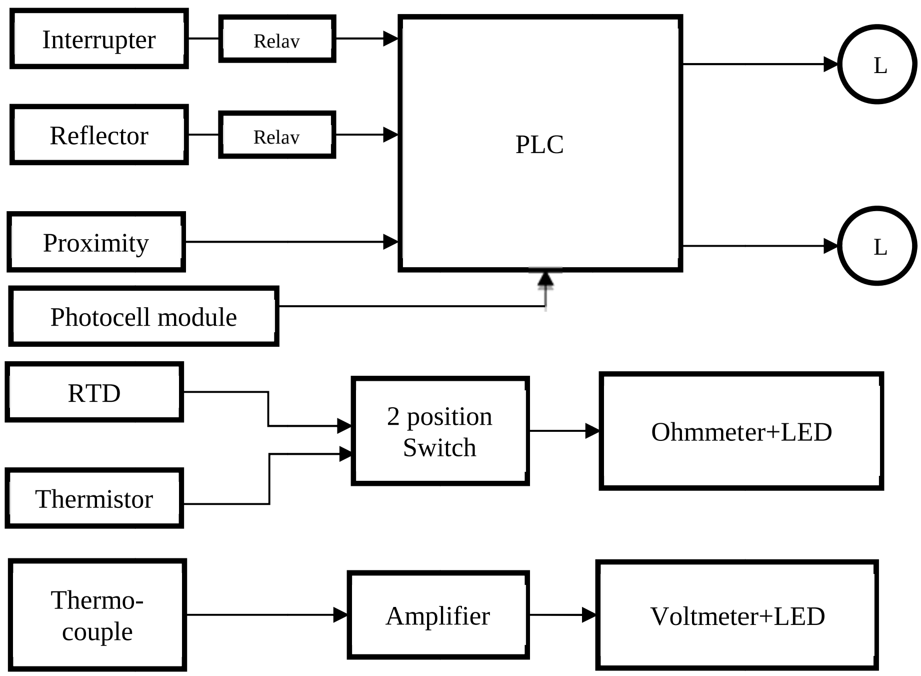

Figure 3. Block diagram of the system

The RTD and thermistor are measured by ohmmeter. Since in this design, both have a resistance range around 100 ohms in 0-40 °C, only one ohmmeter with a range of 0 to 200 ohms is needed. An amplifier amplifies the voltage from the thermocouple to 0-5V range, allowing a voltmeter with a 0-30V measurement range to easily pick it up and show it on an LED display. For proximity and optical sensors, since their outputs are relay outputs, they can interact with the PLC. The PLC also connects with two LEDs to indicate the status of various sensors.

Panel design

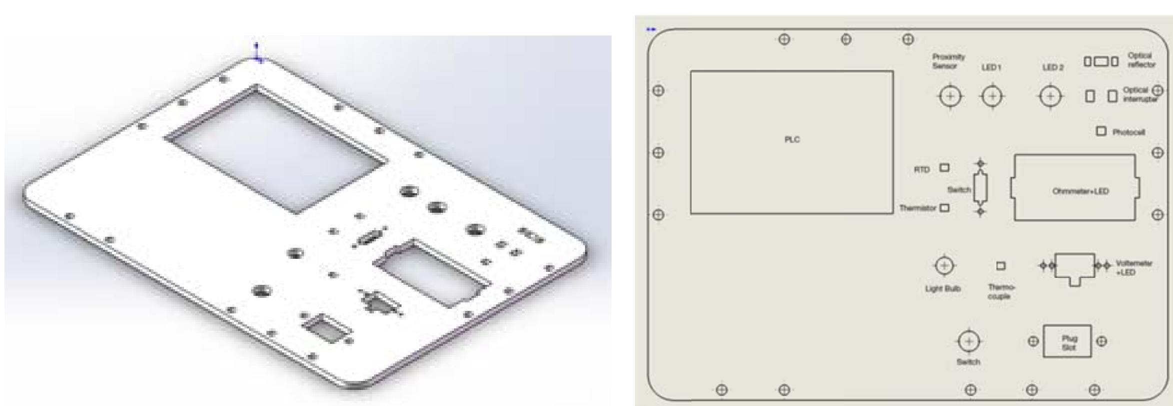

Figure 4. Panel design

The panel (Figure 4) is a Plexiglas board cut using a laser cutter.

Schematic diagram and wiring

For wiring purposes, operating ranges of the various components were identified (Figure 5).

Name	Voltage
Ohmmeter+LED module	8-12V
Voltmeter+LED module	2.7-30V
Integrated optical interrupter	4.5-16V
Integrated optical reflector	4.5-16V
Photocell Switch	12V
PLC Inputs	16-30V
PLC Outputs	4.5V+
Thermocouple amplifier	3-18V

Figure 5. Power Rating for Portable PLC and Components.

Based on this information, it was decided that two converters were needed: a 12V converter for most of the components, and a 5V converter for the optical interrupters (Figure 6).

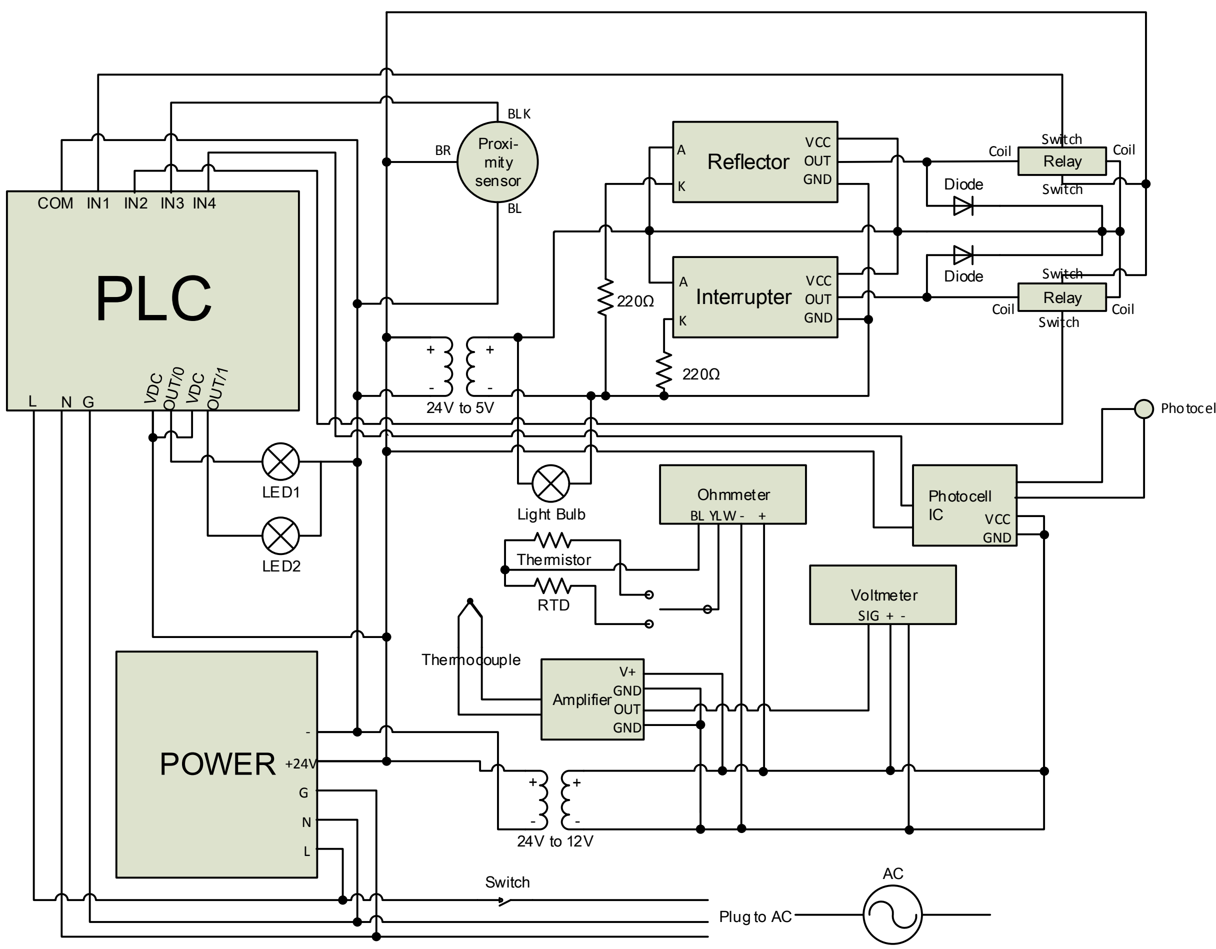

Figure 6. Schematic diagram

Operation of Sensor Module

To start, the power cable needs to be plugged in and the switch next to the power plug socket turned on. The “power” LED on the PLC and the two LED displays to the right of the panel will come on.

Thermal sensors

To use the thermal sensors, users simply touch the model with their hands or other dry object with a temperature that is higher or lower than room temperature. The sensor module also includes a small light bulb that can be pulled out and used as a heat source.

The thermistor is the upper left resistor-like sensor in the middle of the panel. It is connected to the ohmmeter via a two-position switch. Its resistance changes according to temperature. Users access it by (a) changing the two-position switch to the top position, (b) touching the sensor with an object (such as a finger), (c) reading the resistance from the ohmmeter, and (d) converting it to a temperature based on the sensor’s datasheet.

The RTD is the middle (smallest) of the three sensors in the middle of the panel. It is connected to the ohmmeter via a two-position switch. Its resistance changes according to temperature. Users access it by (a) changing the two-position switch to the button position, (b) touching the sensor with an object (such as a finger), (c) reading the resistance from the ohmmeter, and (d) converting it to a temperature based on the sensor’s datasheet.

The thermocouple is the lower probe-like sensor of the three sensors in the middle of the panel. It’s connected to the voltmeter via an amplifier IC. It generates mV level electric potential difference according to temperature. This voltage is captured and amplified by the IC and then measured by the voltmeter. Users access it by (a) touching the thermocouple with a cold or warm object, (b) reading the voltage (in volts) from the voltmeter, and (c) converting the voltage to temperature according to the IC’s specification.

Proximity sensors

To use the proximity sensors, users place a metal object near the probe. When a sensor is triggered, LED 1 will light up.

Optical sensors

To use the optical interrupter, users place a thin object (such as a piece of paper) into the gap of the interrupter to block the infrared light. The interrupter operates in DARK ON mode so its output will become HIGH and LED 2 will light up.

To use the optical reflector, users put a highly reflective object (such as a piece of white paper) about 3mm above the reflector. When the object reflects infrared beam from the emitter back to the receiver, LED 2 will light up.

To use the photocell, users can block the top of the photocell with a finger; LED 2 will light up.

Student Evaluation and Comments

Portable PLC has been incorporated into a Manufacturing Automation and Robotics class since 2014. Students use the Portable PLC units in groups of 2 or 3 to complete exercises on concepts presented during the lectures over a period of six weeks. About 80 students have completed an opinion survey rating various aspects of their experience using Portable PLC on a 7 point Likert scale (1=strongly disagree; 7=strongly agree) (Figure 6).

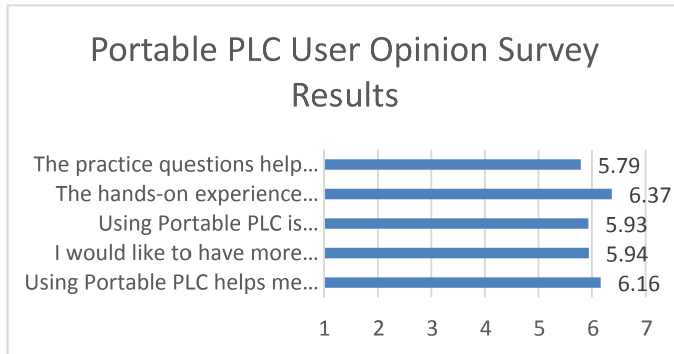

Figure 7. Portable PLC kit in the classroom and Opinion Survey Results.

When answering the evaluation question "The most helpful thing about this teaching tool has been:" a common theme is that students feel that Portable PLC helps them to visualize how the PLC works and to test their programs[10].

Conclusion and Future Directions

Evaluation results suggest that the Portable PLC kits have been well-received by students[10]. Plans for the future are four-fold. First, we will evaluate portable PLC kits with the sensor module. This will allow students to see how sensors and switches are incorporated into real-life applications. Second, we will place some portable PLC kits on reserve in the library so that students can check them out as needed. Third, we will continue designing in-class exercises and homework assignments that incorporate use of the PLC kits with sensor module to enhance experiential learning. Finally, we will evaluate the learning outcomes from this initiative.

Acknowledgements

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