

# Controlling a LEGO Student Factory Using PLCs

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## Introduction

Programmable logic controllers (PLCs) are used extensively in manufacturing, in process control, and in automated testing. The PLC industry generates revenues of approximately US \$1.4 billion from hardware, software, and related services<sup>1</sup>. In addition, the world-wide PLC market is expanding. Over one hundred companies produce a wide variety of products for this market. As a result, PLC programming experience can be a very marketable skill for students entering the workforce. Based on feedback from students interviewing for jobs, a PLC-based course with laboratory was developed to provide students with basic PLC skills.

The laboratory was constructed around the Allen-Bradley SLC 5/03 processor and RSLogix500 software. Six identical lab stations contain an a SLC 5/03 processor, an 8-bit discrete input module (Allen-Bradley 1746-IB8), an 8-bit discrete output module (Allen-Bradley 1746-OB8), and an analog combination module with 2 A/D channels and 2 D/A channels (Allen-Bradley 1746-NIO4V). The processor, modules, and power supply are housed in a seven-slot rack, which allows room to add other modules in the future. The RSLogix500 software is installed on a generic PC, which is connected to the PLC via a serial connection. Students develop their ladder logic programs in the RSLogix software and download them via a serial connection between PC and the PLC. Programs may be uploaded from the PLC to the PC over this same connection.

One of the goals of the laboratory was to provide the students with an end-of-term project that would simulate conditions in an industrial environment. Limited laboratory space and financial resources prevented the acquisition of actual industrial equipment. Many educators have utilized LEGO products for projects and laboratories<sup>2-5</sup>. A LEGO Student Factory was constructed as the basis for the end-of-term project and is shown in Figure 1. A crane is utilized to lift blocks from the floor to the top of the laboratory table. Once a block has reached the proper height, a limit switch turns off the crane motor. Next the pusher arm transfers the block from the lifter plate onto a conveyor constructed using LEGOs. A proximity sensor determines when the block is moved to the conveyor belt and turns on the conveyor belt drive motor. The blocks are sorted, using a sorter car constructed from LEGOs, into two bins based on a predetermined sorting criteria. After the block has been moved to the proper bin, the lifter plate is returned to the floor. This project requires the students to coordinate signals from 8 different inputs and control four dc motors - three with bidirectional capability.

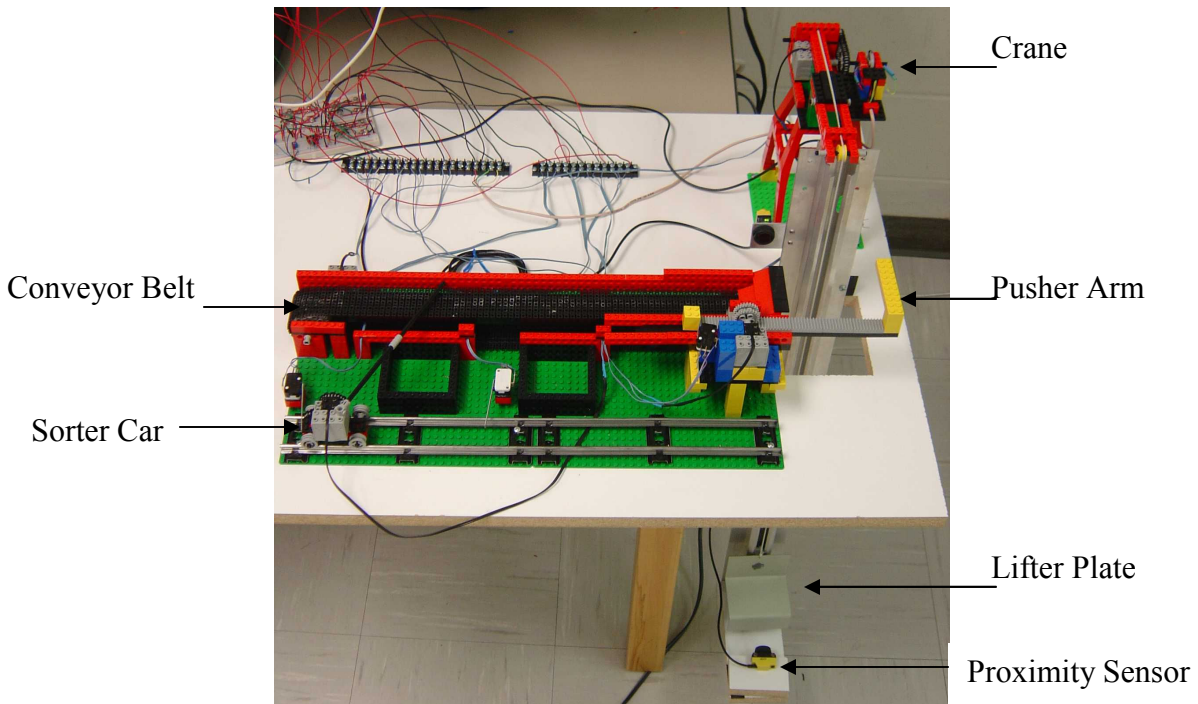


Figure 1. The LEGO Student Factory.

### Laboratory experiments

Students in the course perform ten laboratory experiments to provide the necessary skills for controlling the LEGO student factory. The experiments are as follows:

1. Tektronix TDS oscilloscope and Wavestar software – the objective of this experiment is to familiarize the student with operation of the oscilloscope and the use of the Wavestar software for recording and analyzing waveforms.
2. Basic PLC input and output – the objective of this experiment is to familiarize the student with basic ladder logic and discrete input and output modules. Students connect LEDs to the output module and simple toggle switches to the input module. Ladder logic programs are developed to turn on certain LEDs based on the status of the toggle switches. Students learn how to develop ladder logic programs in RSLogix500 and download them to the PLC. The program RSLinx is utilized to establish the communication link between the PC and the PLC for download and upload of programs.
3. Timers and counters – the objective of this experiment is to familiarize the student with timers and counters – two useful instructions for ladder logic programs.
4. Traffic light controller – the objective of this experiment is to deepen the student's understanding of timer and counter instructions. Students are required to program different scenarios for the operation of a traffic light.

5. A/D and D/A conversion – the objective of this experiment is to familiarize the student with the operation of the Allen-Bradley 1746-NIO4V analog combination module. Student learn how to read data into and send data out of the PLC using this module. Limitations of the module are also explored.
6. Driving a dc motor – the objective of this experiment is to familiarize the student with techniques for driving dc motors. In the LEGO Student Factory, the crane, pusher arm, sorter car, and conveyor belt are driven by dc motors. The first three must have bi-directional capability.
7. Using a proximity sensor – the objective of this experiment is to familiarize the student with the operation of proximity sensors. Two proximity sensors are utilized in the student factory – one senses when the lifter plate has returned to the floor and the other senses when a block has been moved to the conveyor belt.
8. Motor speed measurement – the objective of this experiment is for the student to measure the speed of a LEGO dc motor as a function of applied voltage. The speed at which the crane in the factory lifts the block is controlled. A simple encoder is made using a LEGO pulley, an LED, and an optical receiver. The speed of the motor is determined from the encoder output.
9. Determination of the transfer function of the LEGO motor and sensor – the objective of this experiment is to measure the transfer function of the LEGO motor and sensor, which includes the encoder and other circuitry utilized to provide a speed signal to the PLC.
10. PID controller – the objective of this experiment is to implement a proportional-integral-derivative (PID) speed controller for the LEGO motor on the crane using the PID block in RSLogix500. Using the results from experiments 8 and 9, a PID controller is designed, simulated, and implemented. The end-of-term project utilizes a PID controller to control the speed at which blocks are lifted from the floor to the table.

### The LEGO Student Factory

The crane is shown on the right hand side of Figure 1. A close-up view of the crane is shown in Figure 2. The simple encoder constructed to determine the speed of the crane motor is shown in the front of this picture. A block is placed on the lifter plate shown in Figure 3. The process is started by closing a ‘START’ switch. At this point, the crane motor is energized and begins lifting the block to the table level. The speed at which the block is lifted is controlled using a PID speed controller. The crane motor is de-energized when the lifter plate hits the crane limit switch, which indicates that the block has reached the correct height. At the end of the factory cycle, the lifter plate is returned to floor level. When it reaches floor level, the proximity sensor (Banner Engineering QS18VP6D) in Figure 3 sends a signal to the PLC. The crane motor must have bi-directional drive capability to both raise and lower the lifter plate.

When the crane limit switch is closed indicating that a block is ready to be moved to the conveyor belt, the pusher arm motor is energized to move the block to the conveyor belt. The pusher arm is shown in Figure 4. The motor remains energized until the pusher arm proximity

sensor in Figure 5 indicates that the block has been moved onto the conveyor belt. At this point, the pusher arm motor is reversed to return the pusher arm to its initial state, which is indicated by the closure of a limit switch. This motor must also have bi-directional drive capability. The output of the pusher arm proximity sensor also turns on the conveyor belt shown in Figure 4. The conveyor belt drive motor, shown in Figure 6, only turns in one direction. The speed of this motor must be sufficient to move the blocks on the conveyor belt but not so large as to derail the sorter car. The sorter car, shown in Figure 7, moves left or right depending on the sorting criteria executed in ladder logic. Two limit switches are utilized to control the position of the sorter car. The dc motor on the sorter car must have bi-directional capability. Note that the sorter car rides on a track constructed from model railroad track.

## Project assignment and test procedure

A typical project assignment is as follows:

Use the Student LEGO factory to sort LEGO blocks into two separate bins based on a sorting switch. As an example, if the sorting switch is closed, place every third block in the left bin and other blocks in the right bin. If the sorting switch is open, place every second block in the right bin. Block size and weight may vary.

Design and build all the necessary interface circuits for the factory and operator control.

The operator initiates the factory cycle by a manual switch closure (START button). The only human interaction with the factory is placement of a block on the lifter plate and activation of the START button.

Develop ladder logic to deliver blocks from the floor to the conveyor belt using the crane and pusher arm. Implement a PID speed controller on the lifter plate in the UP direction. Sort the blocks given a prescribed sorting order. Control the conveyor speed to avoid derailing the sorter car. Return the factory to the initial state – defined as lifter plate at floor level, pusher arm to the right (see Figure 1), sorter car to the left (see Figure 1), and the conveyor belt off.

The factory is tested using LEGO blocks of different sizes and shapes. One of the blocks is a weighted LEGO block, which is utilized to test the PID controller on the crane motor and the speed of the conveyor belt. Successful operation of the factory must be demonstrated to the instructor. Each lab group submits a written report and makes an oral presentation on their factory.

## Summary

Described in this paper is a LEGO student factory utilized in a course on programmable logic controllers. It is a low cost, compact setup to simulate industrial process control. Students are required to lift blocks from the floor to a tabletop and then sort the blocks into two bins based on a sorting criteria. They must coordinate signals from eight different input sensors, such as limit switches and proximity sensors, and control four dc motors - three of which must be capable of bi-directional operation. Although no formal assessment has been completed to date, this factory

has proven a convenient platform to bring together a number of course concepts to complete an end-of-term project using the factory.

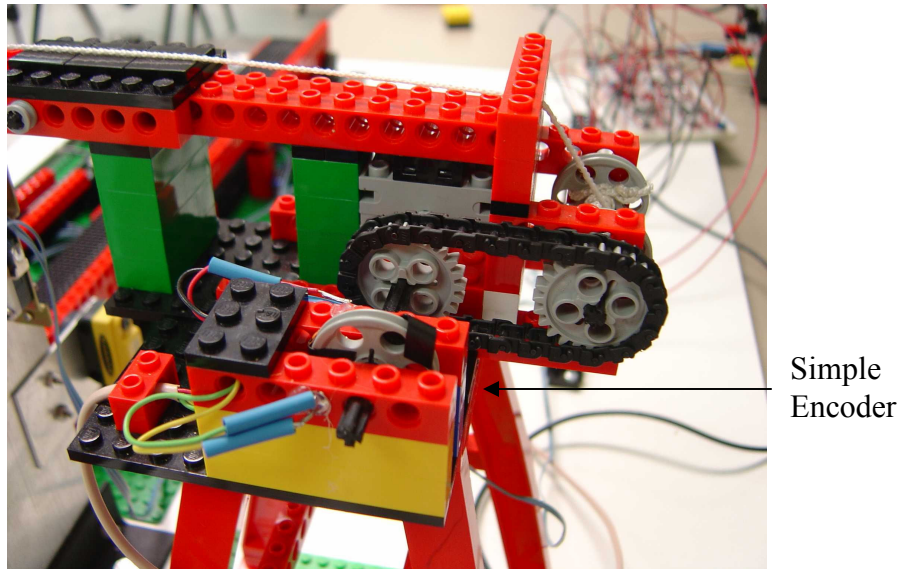


Figure 2. Crane.

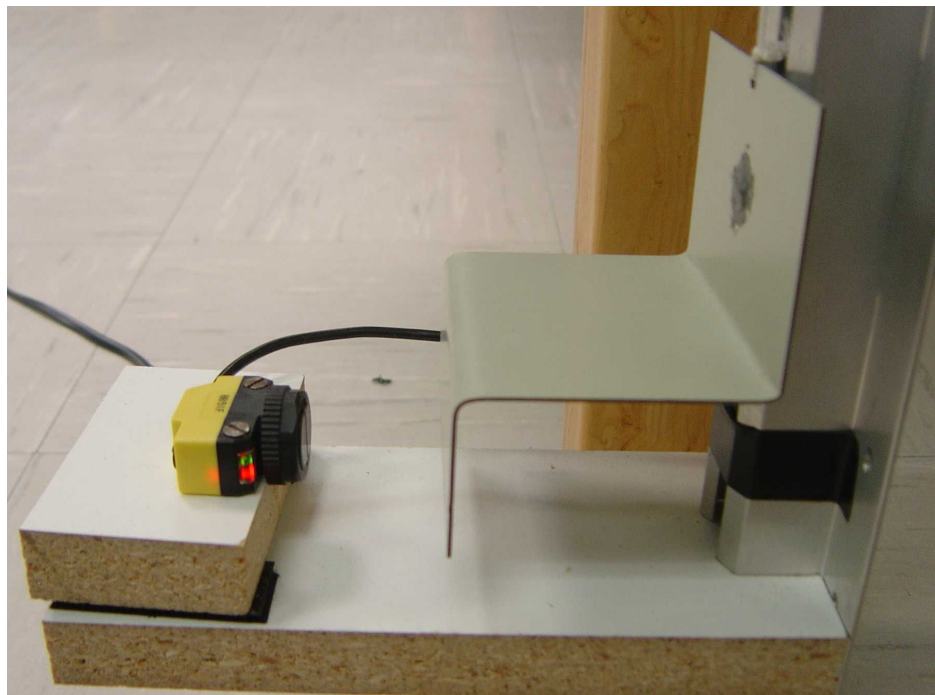


Figure 3. Lifter plate and proximity sensor.

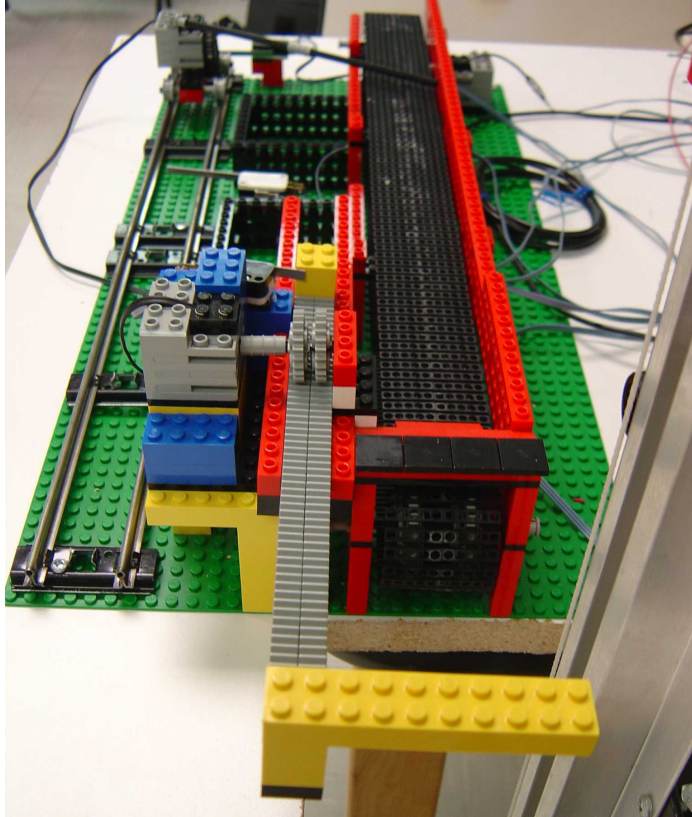


Figure 4. Pusher arm and conveyor belt.

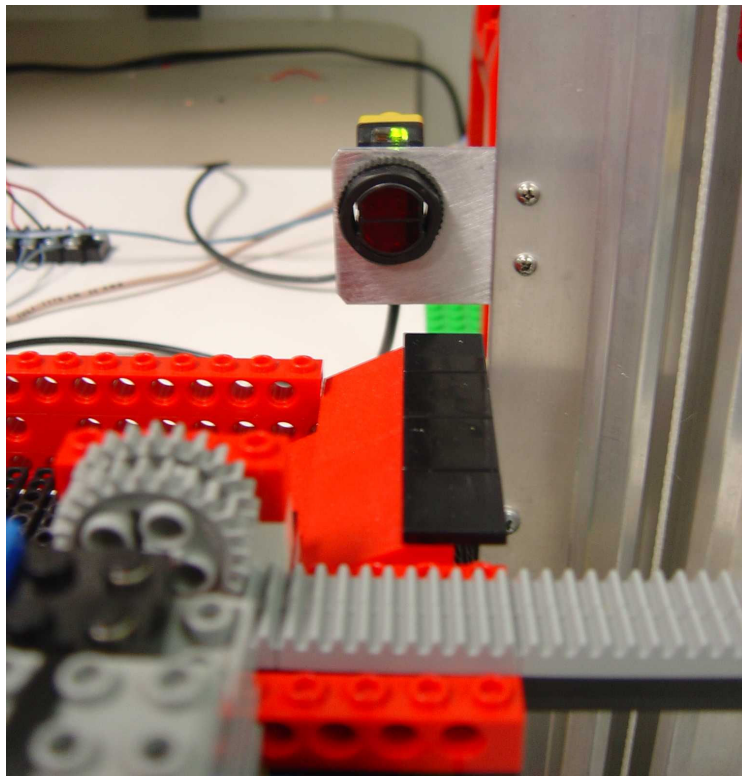


Figure 5. Pusher arm proximity sensor.

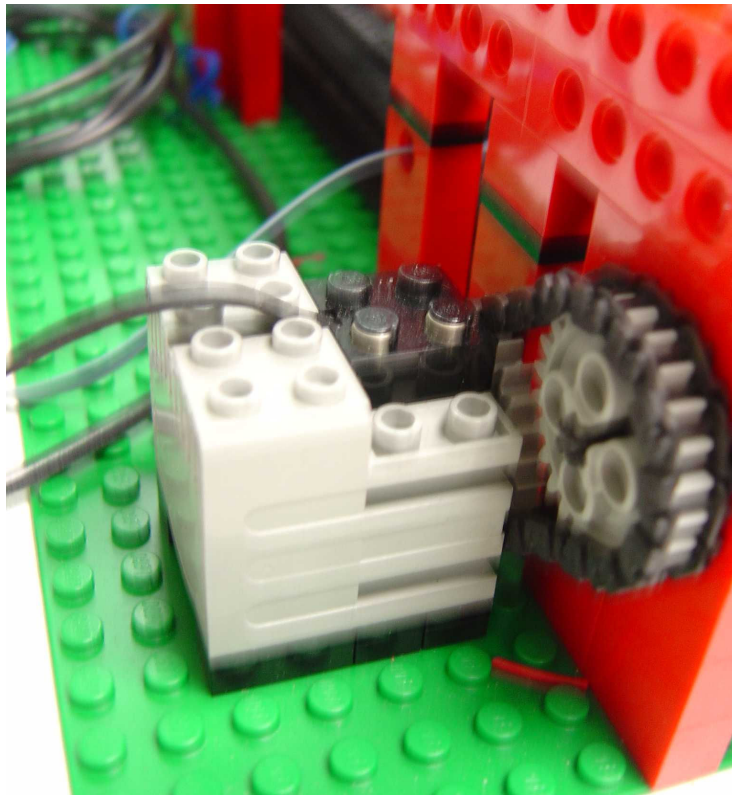


Figure 6. Conveyor belt drive motor.

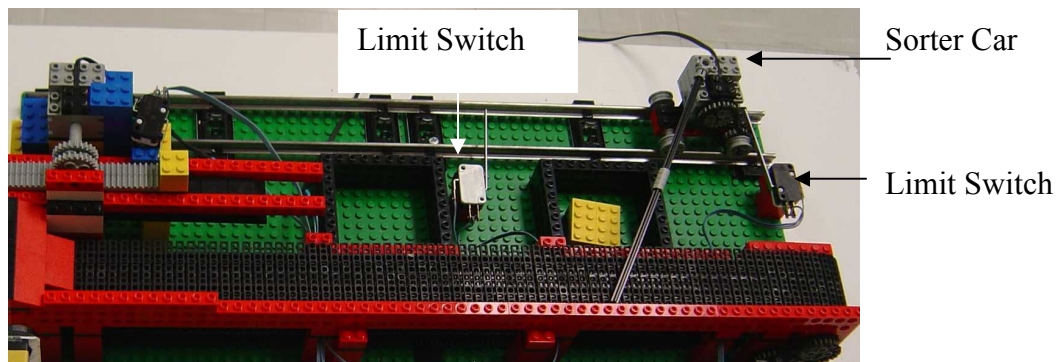


Figure 7. Sorter car.

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