Automated Storage/Retrieval System Design Using Ladder Diagrams and Icon-based Programs

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Abstract

Ladder diagrams have long been used in programmable logic controllers (PLC) for discrete-event process control. For continuous process applications, such as motor rotation, a dedicated and continuous process controller is also necessary. Icon-based programming languages utilize icons to represent sets of functions. Due to their simplicity and user friendliness, use of icon-based programming languages has gradually become a future trend. In this paper, we describe a student project involving the design of an Automated Storage/Retrieval System (ASRS) which utilizes strengths from both ladder diagrams and icon-based programming.

Educational instrumentation by Fischertechnik, which includes a set of building blocks, was used to build a scale model of an ASRS. An associated icon-based program was used to control motor on-off and rotation operations. A PLC was used to determine when and which motor has to be on and in what kind of rotation, given the status of switches on the ASRS. Thus, output from the ladder diagram was used as input to the icon-based program. The motor then moved the crane to the appropriate storage cell. This action resulted in status changes in one or more limit switches. Status changes in the limit switches then triggered output from the ladder diagram. This action resulted in reversal of the motor and return of the crane to its home position. This process would then continue as new parts arrived to be deposited into the ASRS. Two different models were developed successfully for a student semester project.

Benefits of this approach to integrating manufacturing system design within a class curriculum are many. First, the project challenged students to go beyond what they had already learned. Second, this exercise helped students to integrate knowledge learned from different courses, such as electrical system design and computer-aided manufacturing. Finally, the final product from such a project can be used as a demo for prospective students, parents, and visitors; as a project candidate for future groups of students; and as an instructional tool.

1. Introduction

The primary objective of this paper is to demonstrate that ladder diagrams and icon-based programming can be integrated in automated storage/retrieval system (AS/RS) design. An AS/RS is a good representation of integrated automation technology in automated storage system design[1]. However, it is costly to purchase or build scale models for instructional purposes. In this paper, we present a case study in which a scale-model of an ASRS was built using existing off-the-shelf products: a Fischertechnik construction kit and a MicroLogix 1000 programmable logic controller.

2. Background

This section presents some background information about ladder diagrams, icon-based programming, and reconfigurable construction modules (tabletop construction kits).

2.1 Ladder Diagrams

A ladder diagram is a means of graphically representing the logic required in a relay logic system. Ladder diagrams long preceded the programmable logic controller (PLC) and are still used to represent the basic logic required by a relay device or PLC. A basic ladder diagram consists of a series of inputs, timers, and counters. A ladder diagram consists of two rails (the ladder) and various control circuits (the rungs). Each rung starts from the left rail and ends at the right rail, where the left rail represents the power wire and the right the ground wire. Power flows from the left rail to the right rail, and each rung must have an output to prevent a short. The output is connected to physical devices, such as motors, lights, and solenoids. To control the output, switches are used on the rungs to form AND/OR logic. Different rungs are not connected except through the rails.

For the project described here, An Allen-Bradley MicroLogix 1000 programmable logic controller was used to control the discrete events of the AS/RS operations. This PLC provided a limited number of input/output modules (10 inputs and 12 outputs). Figure 1 shows a sample ladder diagram. Brackets [ ] are used to represent an input (e.g., examine a closed condition) and numbers above the brackets signify the input port number. Likewise, parentheses ( ) signify outputs, and the numbers above the parentheses represent the output port number. An input terminal can be connected to a normally open switch; correspondingly, an output terminal can be connected to a motor. The ladder diagram in Figure 1 indicates that if input #1 is true (which means that the switch is closed), the processor should energize the output. In the other words, the motor should be on.

2.2 Icon-based Programming

Marsh[2] noted that an iconic gesture is worth more than a thousand words. Honchell and Robertson[3] observed that icon-based programming has experienced increasingly widespread use relative to traditional/procedural programming languages. Also, in an empirical study, Calloni and Bagert[4] found that people could perform more quickly when using an icon-based programming language than when using a textual/procedural type of language.

In this study, we used an icon-based software package called FiPro to control Fischertechnik modules. In this package, icons are used to represent the shape of physical components. These components include the status of a motor (i.e., an output device), the direction a motor turns (clockwise or counter-clockwise), and the status of a push button. Thus, the status of a push button can be used as an input to determine when to activate a motor and in what direction, clockwise or counter-clockwise. The system provides both digital and analog I/Os, such as a solar sensor reading input; however, there are a limited number of I/Os in each module. Programming is simple: Connect two lamps to the computer interface. In FiPro, point at an icon for a lamp, click on the clock for a delay, and select the icon for the light turned off. This creates a programmed process composed of a sequence of blocks. Add blocks to the process for the second lamp and you have "written" a program. Press the start button and the lights flash on and off. Change the sequence by dragging the blocks to form a different order and a new operation will result. Figure 2 illustrates this example.

2.3 Reconfigurable Construction Modules

Tabletop construction kits are often used to demonstrate the operating principles of automated systems. The tabletop technology system allows a person to mimic a whole range of technological contexts. For example, at the larger end of the simulated scale one can construct a model of a pick-and-place arm with several degrees of freedom. Within the context of the arm alone, the construction and control of its segments may be studied and reconfigured. Fischertechnik components provide the flexibility and functionality needed for educational purposes. Figures 3 and 4 show the basic components provided by Fischertechnik and a constructed scale model of a cargo crane.

3.0 AS/RS Model Design

The development of an AS/RS model can be divided into three stages: planning, preliminary design/testing, and final design/evaluation.

3.1 Planning

In the planning stage of this study, the scope and scale of the problem were investigated. In addition, a preliminary study of the problem was conducted. A typical AS/RS system consists of the following components: storage structure, storage/retrieval (S/R) machine, storage modules (e.g., pallets for unit loads), and pickup-and-deposit stations. The primary issue was to what degree the AS/RS model should mimic the real system. After careful consideration, the following decisions were made:

- Fischertechnik building blocks would be used for model development
- A MicroLogix 1000 PLC would be used for controlling the model
- A smaller scale AS/RS model would be constructed due to the limited number of I/Os in the MicroLogix 1000.
- The model would only mimic the operation of moving the S/R machine to a designated position within the AS/RS.

3.2 Preliminary Design/Testing

Several major tasks were accomplished during this stage. These included:

(a) Design of S/R machine: A motor with a designated track was assembled. Two motor assemblies were mounted on a common platform at a 90^{o} angle to one another. Each motor assembly provides one axis of movement; therefore, the S/R station provided X-Y directions of movement.

(b) Design of storage structure: A unit load AS/RS storage structure was used to build the scale model.

(c) Determination of sequence of operations: The sequence of operations was specified in detail based on the design goals prescribed above.
   (1) When a storage cell within the AS/RS is determined for a given delivery;
   (2) The S/R machine will pick up and move the part to the specified location;
   (3) The S/R machine will move back to the pick-up station;
   (4) Return to Step (1)

(d) An initial model was developed and tested. Due to the PLC's lack of an appropriate analog to digital (A/D) capability, the FiPro software and interface module were used to control and test the model. However, the Fischertechnik interface modules only provided 4 outputs and 8 inputs, so the initial model was limited to a size of 3x2 cells. In order to build a larger scale model, an integration of PLC and Fischertechnik was required.

3.3 Final Design/Evaluation

Two different scale models of an AS/RS were built as a result of this endeavor. One was 3x2, and the other was 3x3. For the 3x2 model, FiPro software (i.e., icon-based programming) was used to control the model. For the 3x3 model, a combination of ladder diagrams and FiPro icon-based programming was used to control the model.

A sequence of events describes the status over time of physical elements such as switches and motors over time, so that a model will accomplish the desired operation sequences. In this case, both models followed the same sequence of events, which was as follows:

(a) Limited switch is pressed and released;
(b) Motor turns in one direction;
(c) Status of another limited switch changes;
(d) Motor stops turning;
(e) Go to Step (a).

In the following sections, we will discuss each model in terms of the sequence of events, its input/output port assignments, and programming.

3.3.1 The 3x2 Model

Since this was a 3x2 model, there were only six storage cells available. Assuming that the pickup station is always in storage cell #1, only five limited switches are needed to indicate the desired location for depositing the material. These five switches represent five different inputs. Also, only two motors (i.e., for horizontal and vertical directions) were needed. Table 1 shows the I/O port assignments.

Figure 5 shows the program written in FiPro. An exhaustive approach was applied in programming the given sequence of events. In FiPro, the "process" is a collection of inputs and outputs. Given an input (such as switch #1 is true), then an icon (such as a motor) will be turned on until the input switch returns to its default status. In Figure 5, each long rectangle represents a process. Each process can run in parallel. For instance, the leftmost rectangle indicates that if key 4 is pressed and limit switch 1 is open, then the motor should be turned in an upward direction until limit switch 4 is pressed.

Table 1. I/O Port Assignments for 3x2 Model.

	Inputs			Outputs	
1	E1	Limit Switch	1	M1	Motor moves in a horizontal direction
2	E2	Limit Switch	2	M2	Motor moves in a vertical direction
3	E3	Limit Switch			
4	E4	Limit Switch			
5	E5	Limit Switch			

3.3.2. The 3x3 Model

This model is controlled by a combination of a MicroLogix 1000 PLC ladder diagram and a FiPro icon-based program. The ladder diagram was used to determine when and which motor has to be on and in what kind of rotation, given the status of switches on the ASRS. This output was then used as input to the icon-based FiPro program. The motor then moved the crane to the appropriate storage cell. This action resulted in status changes in one or more limit switches. Status changes in the limit switches then triggered output from the ladder diagram. This action resulted in reversal of the motor and return of the crane to its home position. This process would then continue as new parts arrived to be deposited into the ASRS. For instance, within the ladder diagram described in Figure 6, the output O:000/00 is used as an input E2 to the FiPro program described in Figure 7. The motor M1 would be on until limit switch E2 is no longer being pressed. As the status of limit switch E2 changes, another rung within the ladder diagram is triggered. Therefore, another output O:000/04 within the ladder diagram is activated; this output O:000/04 then becomes input E5 to the FiPro program. Another motor M2 will be triggered, and the S/R machine will be sent to the pickup station as the result of this action. Figure 8 shows the final design of the scale model; figure 9 shows the students involved in this project.

4.0 Summary and Future Directions

In this paper, we have demonstrated that integration of icon-based programming and ladder diagrams is a feasible solution in controlling a system such as an AS/RS, which includes both discrete and continuous events. Two AS/RS models were constructed using Fischertechnik components. This integration enhanced the availability of I/O ports from each controller and opened a new avenue of integration between an existing controller and a newly installed controller for process control.

Benefits of this approach to integrating manufacturing system design within a class curriculum are many. First, the project challenged students to go beyond what they had already learned. For example, although they had learned about ladder diagrams and icon-based programming separately, this project gave them an occasion to combine the two. Second, this kind of exercise helped students to learn to integrate knowledge from different courses, such as electrical system design and computer-aided manufacturing. Finally, the final product from such a project can be used as a demo for prospective students, parents, and visitors; as a project candidate for future groups of students; and as an instructional tool.

Future directions include the development of a central computer which can keep track of the availability of each storage cell within a AS/RS; and adding a retrieval function to the S/R machine. In addition, the scale model of the AS/RS can be incorporated into other systems, such as production systems and material handling systems.

Bibliography

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Sheng-Jen ("Tony") Hsieh is currently an Assistant Professor at Texas A&M University, College Station, Texas. He received a Ph.D. in Industrial Engineering with a minor emphasis in Computer Science from Texas Tech University. Dr. Hsieh has been involved in teaching and research in the areas of robotics and automation, machine vision, simulation and modeling, and computer-integrated manufacturing for the past four years. He also has four years of industry experience in the automotive and electronics industries. Recent industry/military clients include Texas Department of Transportation, Johnson Control (Reynosa, Mexico), Whirlpool Corporation (Reynosa, Mexico), and the U.S. Air Force.

JUAN ANDRADE, ANA CABRALES, VERONICA MARTINEZ

Juan Andrade, Ana Cabrales, and Veronica Martinez were all undergraduate Manufacturing Engineering students enrolled in Dr. Hsieh's Automation and Robotics course at the University of Texas–Pan American. The work described here was their semester project.

Figure 1. Sample ladder diagram.

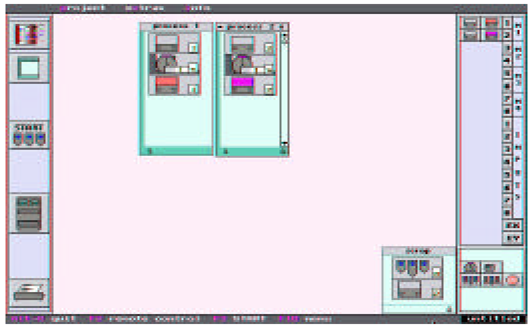

Figure 2. Sample FiPro icon-based program

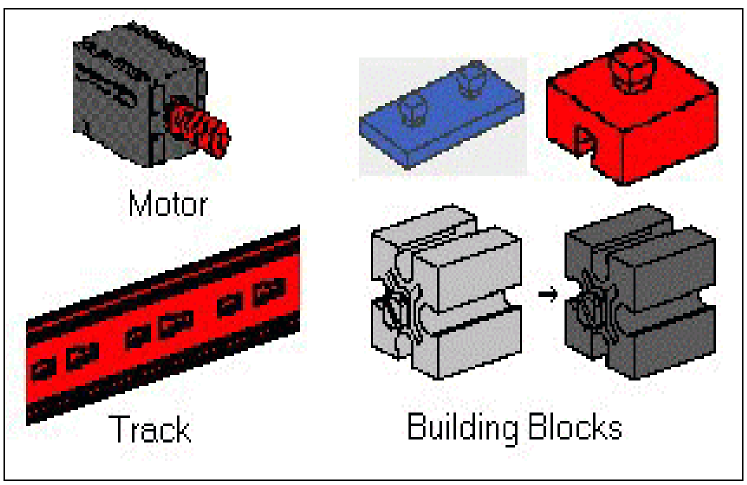

Figure 3. Fischertechnik construction kit components

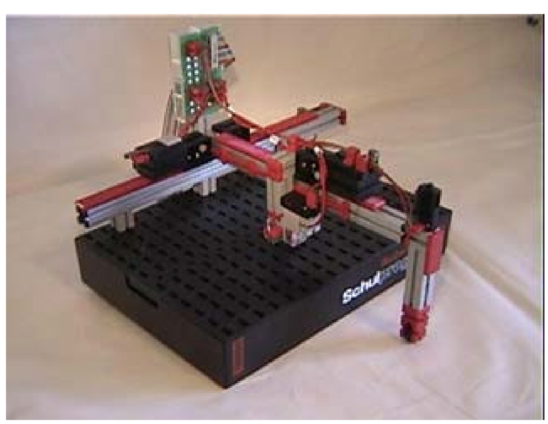

Figure 4. Scale model of a cargo crane

Figure 5. FiPro program for 3x2 AS/RS model

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Program Listing Report                    PLC-5/15    File ASRS

|  I:000 I:000 O:000                                            O:000 |
+-+-] [-+-]/[-+-] [-+-----------------------------------------------( )--+
| |    02|    11|    00|                                           01 |
| |I:000|      |I:000|                                                |
| +-] [-+      +-] [-+                                                |
| |    10|          01                                                |
| |I:000|                                                             |
| +-] [-+                                                             |
| |    05|                                                            |
| |O:000|                                                             |
| +-] [-+                                                             |
|      01                                                             |

v                                                                     v
v                                                                     v
v                          Abbreviated Version                        v

|  I:000 I:000                                                  O:000 |
+-+-] [-+-]/[-------------------------------------------------------( )--+
| |    02|    12                                                   04 |
| |I:000|                                                             |
| +-] [-+                                                             |
| |    10|                                                            |
| |I:000|                                                             |
| +-] [-+                                                             |
| |    05|                                                            |
| |O:000|                                                             |
| +-] [-+                                                             |
|      04                                                             |
```

Figure 6. Ladder diagram for 3x3 AS/RS model.

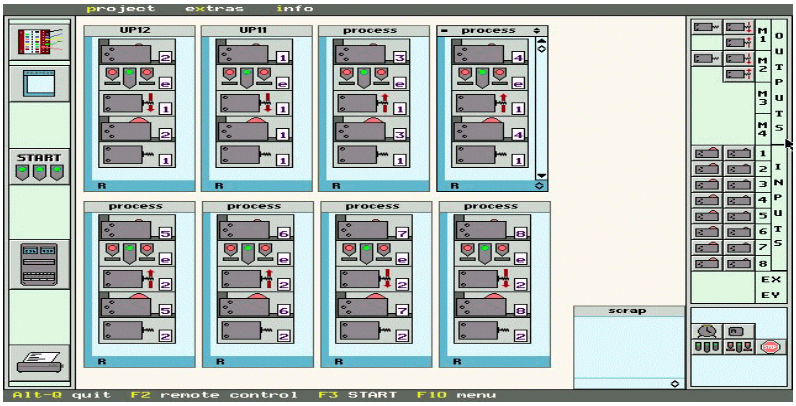

Figure 7. FiPro program for 3x3 AS/RS model

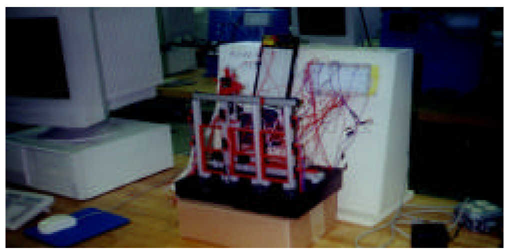

Figure 8. Final design of 3x3 AS/RS scale model

Figure 9. Students involved in AS/RS project