Design, Build and Remote Control of a Miniature Automated Robotic Sorting System

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ABSTRACT
Programmable logic controllers (PLCs) are used in industry to monitor and regulate automated processes. While many processes may be automated, color sorting provides a single example and is used to impact the traits of a finished product. With the development of the internet, there is also increased demand and capacity for remote management of such systems. The performance of remote management is dependent on the implementation methods used. While internet control is typically designed for personal computers (PCs), there has been research done on use of mobile devices. In order to better prepare students for work in industry, education regarding current technology and processes is important. However, it is often inconvenient or impossible to visit and observe actual facilities. Given this limitation, an alternative is to create trainer sets that use or emulate key features of real industrial systems. This research describes the design, build, and validation of a trainer set using a custom demonstration module. Furthermore, the research implements internet-based remote control for use with PCs. Future work could evaluate the performance of various sets of server software with respect to remote control. Also, additional features could be incorporated such as remote programming.

General Terms
Automated system design

Keywords
Programmable logic controllers, remote operation, automated systems

1. INTRODUCTION
1.1 Programmable Logic Controllers
A programmable logic controller (PLC) is a solid state device used to read binary inputs and set binary outputs. It is designed to replace traditional hardwired networks used in manufacturing facilities. While limited to binary inputs and outputs, PLCs are more durable than typical microcontrollers. Furthermore, the input, processor, and output circuitry are isolated from one another, which minimizes the risk of electrical damage to the system [1]. Although PLCs are already widely used, their use continues to grow. One reason is that PLCs are good at managing automated processes. A second reason is the convenience of rewriting programs rather than physically rewiring machines and electrical components on the factory floor [1] [2] [3].

1.2 Internet Control
With the development of computer networks, there is an increasing desire and ability to connect single and multiple PLCs to other computers. In doing so, the PLCs and the processes they control can be monitored from either a single or multiple locations as desired. Locations may also be mobile rather than stationary. In addition to monitoring, networks also allow for remote reprogramming and error handling [3]. This advantage has encouraged research into methods for interfacing with PLCs through the internet. Some methods use licensed software while others, such as the method proposed by Radwan & Martin [4], do not. It has been shown that the use of simpler, non-license software can provide faster response time for remote interaction [4]. Typical interfacing designs involve the use of a personal computer (PC). Such designs are proposed in [2] [3] [4] and [5]. However, Wu et al. [6] propose an interface compatible with cellular (cell) phones. Due to continued development, cell phones are becoming more available, computationally powerful, and portable. By interfacing through cell phones, interaction with PLCs is more mobile and convenient than with the use of PCs [6].

1.3 Color Sorting
Color sorting is used in the food industry as a means of controlling the properties of a finished product. Falconer et al. [7] discuss the application of color sorting to the wine fabrication process. Whether grapes are harvested by hand or by machine, they are mixed with non-grape materials and substandard or damaged grapes. By using color sorting to remove unwanted materials prior to the fabrication process, the content of the resulting wine is noticeably changed. Wine produced from sorted grapes has a higher level of phenol and an increased floral aroma [7]. Color sorting can also be used to determine fruit maturity. As described by Sirisathitkul et al. [8], determining fruit maturity is important for both selling and transporting fruits. For example, the presence of overripe fruit can hasten the ripening process for neighboring fruit. Sirisathitkul et al [8] found that a teachable hue-based color sorting system could categorize chokun oranges by maturity with 98% accuracy.

Color sorting has been applied to products other than fruit. For instance, Szabó & Lie [9] used a web camera and blob filters to sort cubes of various colors. While Szabó & Lie provide only a laboratory view of color sorting, Lu et al. [10] provide a tested industrial application. In the production of glued wood panels, uniform color is desired for aesthetic reasons. However, manual sorting of boards requires much time and effort from experienced employees. Through use of three-dimensional color histograms, custom image processing boards, and web cameras, wooden boards of various sizes were sorted into seven color groups with over 90% accuracy. Furthermore, Lu et al. [10] were able to achieve this at speeds acceptable for mass production.

1.4 Purpose

In order to prepare students for work in industry, it is preferable to provide education regarding current technologies and processes. However, visits to industrial facilities, if possible, are likely to provide demonstrations rather than actual experience. An alternative is to create trainer sets which use or emulate key aspects of actual industrial systems. This research has three major objectives. The first objective was to construct a trainer set. Students would then be responsible for building an automated system module and writing associated code for the PLC. Another objective was to design and build an example module that demonstrates color sorting. This module also served to validate the trainer set. Finally, a remote control interface was created to allow access through the internet from PCs.

2. METHODOLOGY

2.1 Trainer Set

Construction of the trainer set (see Figure 1) was partly based on work previously done by the laboratory. A plastic portable case (about 12.5 in. x 9 in. x 5 in. (31.8 cm x 23 cm x 13 cm)) was used as the main housing to hold and transport both the trainer set and the module. An Allen-Bradley MicroLogix 1000 (16 I/O points) PLC was mounted on an acrylic base plate. Also mounted to the base was an alternating current (AC) to direct current (DC) voltage converter (TDK-Lambda LS50-24). This was used to convert from the wall voltage (United States 120 VAC) to 24 VDC. A DC to DC voltage converter (LM2596-SDC) was then mounted on top to provide 9 VDC. The base plate was attached to the case using

Figure 1: Trainer Set

a Velcro-like fastener. In addition to the base plate, a cover plate was made. The cover plate includes a hole so that the PLC can be connected to a computer without removing the plate. The plate also includes an electrical socket for connection to a wall electrical outlet and a switch to turn the system on. The cover plate was mounted to the case using screws and hinges. Necessary wiring of the components was completed (see Figure 2). Additionally, a ribbon cable was used to allow connection of modules to the PLC. The trainer set was assembled such that there would be space (about 8.5 in. x 5 in. x 5 in. (22 cm x 13 cm x 13 cm)) remaining for a demonstration module to be stored for transport.

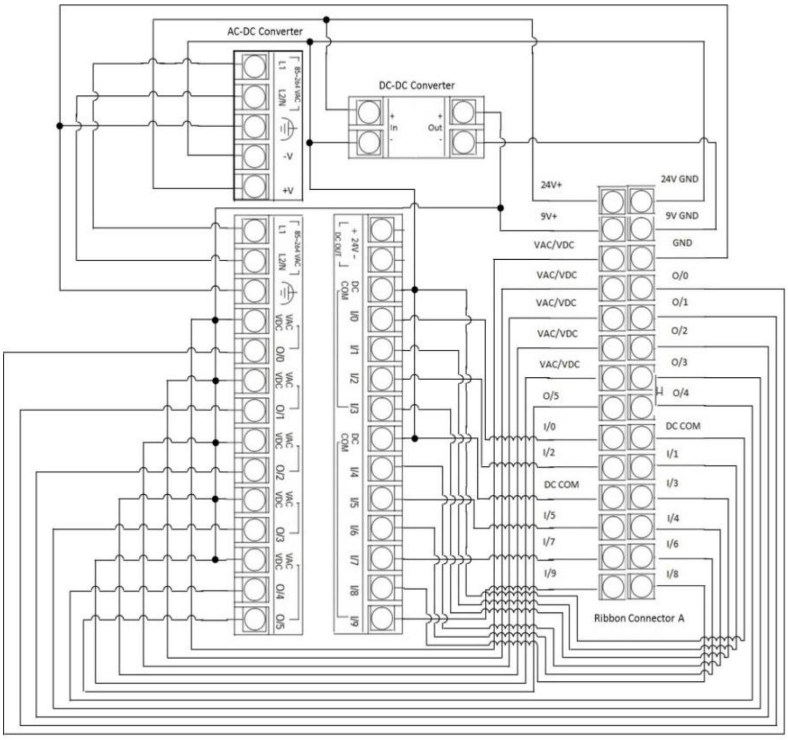

Figure 2: Schematic of Wiring for Trainer Set. Note that ribbon connector A is connected to ribbon connector B (in Figure 4) through use of a ribbon cable. Also note that the AC to DC converter is connected to the external power source (United States 120 VAC).

2.2 Demonstration Module

There were several constraints on the demonstration module. Foremost was the size constraint. As previously mentioned, the trainer set was assembled to leave space in the case for the module. As such, the module needed to be within 8.5 in. x 5 in. x 5 in. (22 cm x 13 cm x 13 cm) so that it could be stored with the trainer set. A second constraint was availability of parts. Lego and Fischertechnik parts were the most readily available and thus were used to construct most of the module.

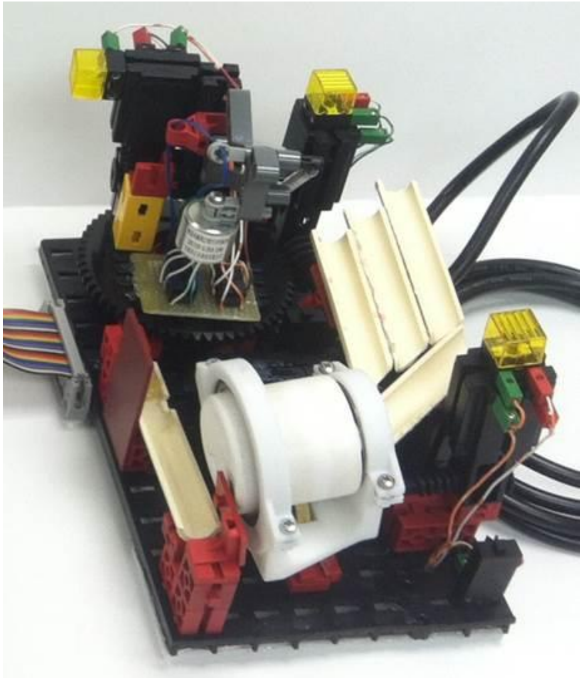

Figure 3: Demonstration Module

There are four major components of the demonstration module (see Figure 3) that required significant consideration. Those components are the robotic arm, the grip, the mixing mechanism, and the color detection system. Additionally, chutes were constructed from polyvinyl chloride (PVC) pipes (0.625 in. (1.6 cm) inner diameter) and used to transport painted bearing balls from one location to another. The various electrical devices in the module were wired according to Figure 4.

2.2.1 Robotic Arm

Although there are many methods for physically sorting items, it was decided that a robotic arm would be used. Multiple ideas were explored with respect to achieving vertical motion. The initial design proposed a jointed arm controlled by a gear system. The major issue with this particular design was availability of parts. A second design was proposed in which the arm remained static vertically and a pulley system moved the grip. This method was implemented first. However, brief testing showed that the mechanism was too imprecise to be used. Furthermore, the required height for the arm exceeded the limit imposed by the trainer set. The vertical motion was finally achieved by use of a four-bar linkage assembled from Lego parts (see Figure 5). The linkage was fixed to a column present in the arm assembly and a tension spring was added to provide a return mechanism. In order to lift the end of the arm, a pulley-like system was implemented. Wire was wrapped around the axle of a motor, passed over the top of the previously mentioned column, and tied to the end of the arm. This method had two main advantages over the pulley system. One advantage was that the horizontal position of the four-bar linkage could be controlled more precisely. The other main advantage was the required height. By attaching the wire to the grip location, the dynamic height of the arm could exceed the height of the vertically static components. This allowed the arm to obtain sufficient height during operation yet have a storage position compliant with the limitations imposed by the trainer set. The majority of the robotic arm was constructed using Fischertechnik parts and mounted on a turntable. Horizontal motion was obtained by connecting the turntable to a motor through use of a worm gear. Since both motors were basic DC motors, additional components were required in order to successfully operate the arm. A double pole double throw relay was used for each motor to control the direction of rotation. Additionally, cogwheels and push buttons were used to track the position of the robotic arm relative to its initial location.

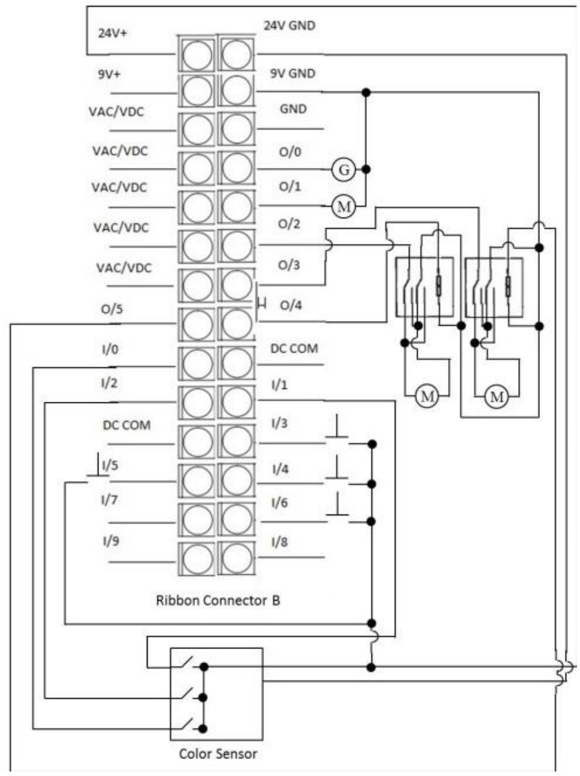

Figure 4: Schematic of Wiring for Demonstration Module. Note that ribbon connector B is connected to ribbon connector A (in Figure 2) through use of a ribbon cable. Also note that G denotes the grip; in this case, an electromagnet.

2.2.2 Grip

There were also multiple ideas considered for the gripping mechanism. A traditional mechanical grip was briefly considered. However, this concept was not favored due to the additional dynamic components required. A vacuum system was also considered. Given the size restrictions, typical commercially available air evacuators could not be used. Therefore, a substitute system as constructed through use of Fischertechnik components. While the vacuum system was successfully created, it was still too large for the module. As a result, use of an electromagnet was implemented (see Figure 5). The electromagnet is advantageous because it is small

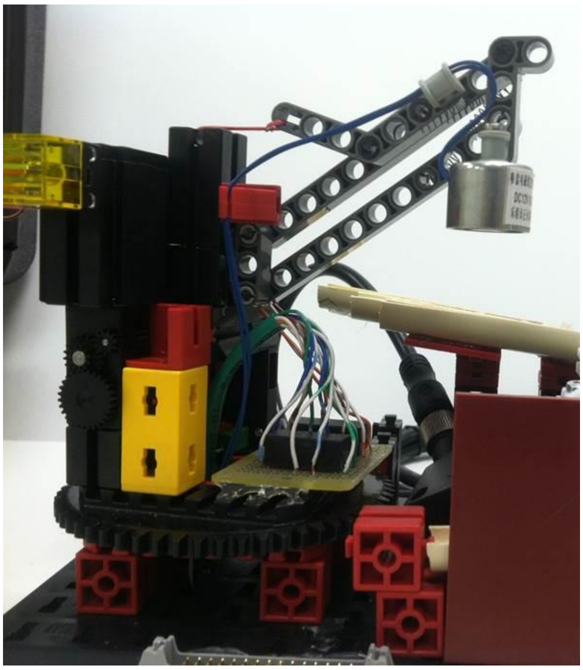

Figure 5: Robotic Arm and Grip

(diameter about 0.75 in. (1.91 cm); height about 0.5 in. (1.3 cm)), has a firm grip, and can be easily mounted at the end of the robotic arm. Consequently, painted metal bearing balls were used as the objects to be sorted. One issue with the electromagnet was that it could grab multiple balls. The voltage applied to the magnet was decreased to mitigate this effect, but additional compensation had to be done though the drum design and the PLC program.

2.2.3 Drum

Since the module was for demonstration, it needed to be a closed loop system capable of remixing the balls. Size was the deciding factor leading to the use of a small drum (rotating cylinder) as the mixing mechanism (see Figure 6). The drum was constructed by modifying a plastic medicine canister. Ball bearings were then placed at the two ends to reduce friction. However, since high speed bearings were used, the grease provided a significant source of resistance. Custom 3D-printed parts (see Figure 7) were assembled into a stand to hold the drum in place. A small wheel was placed on a shaft attached to a third motor. The wheel was held in place by the stand under the drum such that friction would cause the drum to rotate. Chutes, inclined at 7.5 degrees (about 0.13 rad), were used to transport the balls from one location to another. One issue was controlling the balls such that only one came out of the drum per full rotation. Although this problem was not fully solved, it was minimized by the addition of a wall. The wall was positioned so that balls could exit the drum only during a fraction of a rotation.

2.2.4 Color Sesnor

To detect colors, an Allen-Bradley 45CLR ColorSight was positioned between the drum and the ball pick-up location. The sensor was programmed to detect three different colors with tolerances set as needed. One issue with the color sensor was that, upon detection of a color, the output signal would occasionally be too brief for the PLC to detect. This problem was fixed by use of the sensor's pulse stretching function. The pulse stretching function ensures that the output signal will be active for a minimum duration of time after detection of a desired color.

Figure 6: Drum Assembly

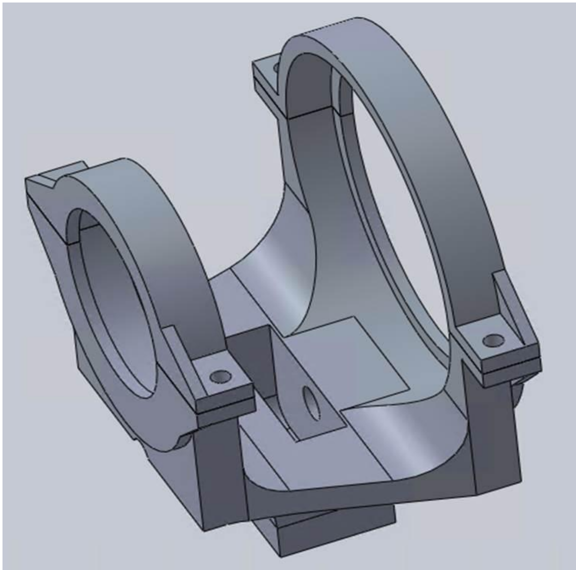

Figure 7: CAD Model of Drum Stand Assembly

2.3 PLC Program

2.3.1 Start-Up

Since the demonstration module was designed for travel, the initial physical position of the robotic arm did not correspond to an ideal position for the start of a sorting cycle. As such, an attempt was made to provide an initialization sequence as part of the ladder logic program. However, the module design does not allow for knowledge of the position at start-up and does not contain limit switches. As a result, all attempted solutions through programming were not reliable. The final solution was to require the operator to manually set the initial position and program the PLC to start with an assumed initial position. Although this approach was meant to solve the initialization issue, it actually addresses a more general concern. After turning the module off, the operator is free to manipulate the arm. Thus, there could be changes in position that are not registered by the PLC. By assuming a particular start position, the module requires fewer sensor components.

2.3.2 Color Detection

As previously mentioned, an Allen-Bradley 45CLR ColorSight was used to detect the colors of the bearing balls. Since the sensor energizes an output only when the corresponding color is present, the PLC must "remember" which color is currently in the system. Another requirement is that the arrival of a ball does not interfere with the sorting of a prior arrival. In order to comply, the PLC must either queue the detected colors or delay recording the new color until the current ball has been sorted. For simplicity in the program, the latter method was used.

2.3.3 Color Sorting

Once the color of a ball has been detected, the PLC energizes the motors in sequence. The relays are energized when the direction of rotation needs to be reversed. As previously mentioned, cogwheels and push buttons are the hardware used to track the position of the robotic arm. Each color has its own set of counters with each counter tracking the progress of a particular portion of the sorting cycle. When a cogwheel depresses a button, the appropriate counter is incremented. The actual sorting was accomplished by varying the preset values among the different colors. In doing so, the arm moves to different positions depending on the detected color.

2.3.4 Regulating Ball Flow

The program was another means by which the grip was limited to one ball per cycle. Two methods were tried; both of which manipulated the operation of the drum. The first was to periodically turn the drum on and off. This would provide more time between the releases. The issue with this method is that the position of the drum's outlet could not be controlled with enough precision. Furthermore, it was more difficult for the balls to exit the drum. The second method was to energize the drum until a color is detected. The drum would then be turned off until the sorting cycle is complete. The latter method was used for the final implementation.

2.4 Internet Control

An Apache server was set-up to host a web page and the necessary scripts and applications. The web page was written using Hypertext Markup Language (HTML) and provides the user with start and stop buttons as well as live video of the system from a web camera (see Figure 8). The video is retrieved from a separate webcam server. When either button on the web page is clicked, a PHP script writes to an output file which is then ready by a Visual Basic (VB) application. The VB application then communicates with the PLC to either activate or deactivate the system.

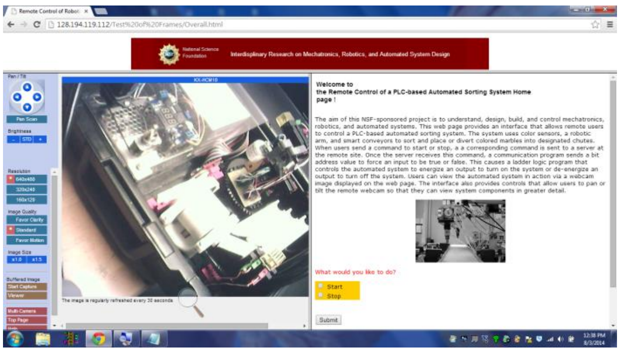

Figure 8: Internet Control of Automated Robotic Sorting System

3. CONCLUSION

There were two objectives for this research. The first was to create a trainer set that could be used by students. Students would then be responsible for constructing their own automated system modules and associated code. The next purpose was to create a module to demonstrate both the trainer set and color sorting. It was decided that a robotic arm and an electromagnet would be used to sort painted metal bearing balls. A drum was constructed to remix the balls so that the module would be a closed loop system. Both goals were successfully met. The demonstration module was able to complete sorting cycles with approximately only one error every 25 cycles. In no instances were serious or complicated errors encountered. Further research could include creation of multiple web pages each using a different set of software. Data regarding the performance of remote control could then be collected to compare the software. Also, more functions could be incorporated such as remote programming. Once created, the remote control system could also be used to further enhance education by serving as a remote access lab. As stated by Aydogmus [11], remote access labs have the potential to provide cost effective, hands on experience to many students.

4. ACKNOWLEDGMENTS

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