

Affordable Innovation on Collaborative Programming and Configuration in Programmable Logic Controller (PLC)

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Abstract

This paper illustrates an affordable approach into the previously developed integrated programmable logic controller (PLC) design and implementation learning platforms [1]. Affordability, in this context, means at no additional cost to the developer by using dual PLCs to resolve system limitations. When dealing with the problem of how to maximize the use of the finite number of inputs and outputs that a PLC has available for use, acquiring an upper tier PLC module is a typical option. The proposed method, however, adapts the so-called PLC domain knowledge model to deliver a fool-proof solution systematically. In this regard, all available assets are fully utilized before considering a PLC upgrade.

By applying input and/or output mapping, dry contacts, and control relay concepts on the PLC, one can lay out a strategy for hardware and software implementation. Most importantly, such distributable information enables collaborative efforts among developing team members.

As a hands-on concept-proof module, a system of a scaled three-story elevator model is described in this paper. Additionally, the system is compact enough to be portable. This system is also expandable, leaving the possibility for future expansion and development quite accessible to the developing team who may wish to add onto or adapt the system as the need arises. Finally, extensions of the proposed approach applied to the PLC applications in the system are discussed.

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Keywords: programmable logic controller (PLC), collaborative programming and configuration

1. Introduction

Programmable Logic Controllers (PLCs) were designed to replace electromechanical relays. Since their invention and introduction, they have steadily gained widespread use throughout industry and academia. The PLC's rugged design allows it to be used in harsh environments that are unsuitable for a normal computer. PLCs can also be reprogrammed and adapted to suit the needs of an array of automation scenarios. They are well suited to dynamic manufacturing environments in which the automation processes are continually being changed to meet different consumer needs. For these reasons, PLCs have become and will continue to be a major part of industry well into the 21st century. As PLCs become more commonplace in industry, there will be a definite need for those who can integrate PLCs into the manufacturing environments effectively and efficiently.

As members of the academic community, we the authors continually strive to find new ways to both engage with and challenge our students in order to give them the best possible learning experience. One of the tools which we employ to help us accomplish this goal are scale model PLC systems. We first began to use scale model PLC systems in an attempt to give students hands on experience with both PLC and sensor hard wiring. When used in combination with other traditional and virtual learning tools, we found this approach to be an effective learning tool [1-9]. The model PLC systems allow the students to gain knowledge in the physical wiring of sensors to the PLC,

something that is best learned through a hands-on approach.

2. Background and motivation

The first models we developed for use in the classroom were quite straightforward in comprehension, typically involving back and forth reciprocal motion. In later designs, we began to model more challenging and complex systems in an effort to give students not only more of a challenge but also more knowledge in PLC programming and wiring. Throughout the process of designing new PLC system models for use in the classroom, we encountered one recurring problem, that is, that our selected PLC, the MicroLogix 1000, has a limited number of inputs and outputs for use. Later, however, this proved to be somewhat advantageous to us as it allowed us to introduce the students to a fundamental concept in PLC system design, that is, knowing precisely what a PLC system will require in terms of inputs and outputs so that the appropriate PLC can be selected. A PLC with a larger number of available input and output ports will typically cost more than a PLC with fewer available input and output ports, and as such it is very important to select the appropriate PLC for the desired PLC system in order to avoid excess cost. Although the MicroLogix 1000 has a limited number of input and output ports available, it is also very affordable and compact, making it ideal for use in the classroom. So rather than upgrading our PLC we sought to find ways to maximize that which we already had available. This decision proved to be beneficial for us since working with finite resources we developed a systematic approach to aid in PLC system design, which allowed us to consistently better utilize all of the PLC input and output ports. This system will be outlined in the coming section of this paper.

One model which we developed for use in the classroom was the model of a three-story elevator which allowed the students to design and build their own fully functional, albeit

simpler in operation than its real world counterpart, three-story elevator. To accomplish this, the issue of the MicroLogix 1000's somewhat limited number of input and output ports had to be addressed. Precisely how this was done will be outlined in the later section of this paper. The reason why we opted to have the students construct a three-story elevator, as opposed to a two-story elevator, is two-folds. First, it allowed us to introduce some practical applications to knowledge that the students had gained throughout the course of the semester, namely the use of binary logic as well as how to design a PLC system. Second, it required a determination of the number of inputs and outputs needed to control aforementioned PLC system.

Typically, the students build the three story PLC model at the end of the semester after they have built different simpler projects. This project is the culmination of their work throughout the semester and offers them the chance to apply the knowledge they have learned to a practical application while gaining hands on experience with PLC hardwiring.

3. Method

The aim of our research within the design and construction of scale model PLC systems is to seek new ways to expand the limits of our existing technology thereby allowing us to achieve maximum utilization from our limited resources. As such, we have developed several tools for use when designing new PLC systems, either in full scale or model. The latter portion of this paper will focus on a method we have dubbed *collaborative programming* which allows for two PLCs to communicate with each other in such a way that they can simultaneously be used to control the same PLC system.

- 1). Input and output mapping: this paper treats it as a schematic(s) depicting all of the PLCs inputs and outputs and their wiring and subsequent relationship to other inputs and outputs in the PLC system.

The input and output maps serve as graphical tools for organizing and representing the PLC program and the PLC input and output configuration. They are of great use when more than one PLC is to be used in a system, or in the more general case, as a PLC system becomes more complex in nature.

- 2). Dry contacts: an output voltage is connected to a voltage free contact, based upon the wiring diagram shown in Figure 1 in MicroLogix 1000 User Manual [10]; whether it is opened or closed, there is no voltage on the contact until the specific terminal is activated. Therefore, we consider the output connections of the PLC as dry contacts.

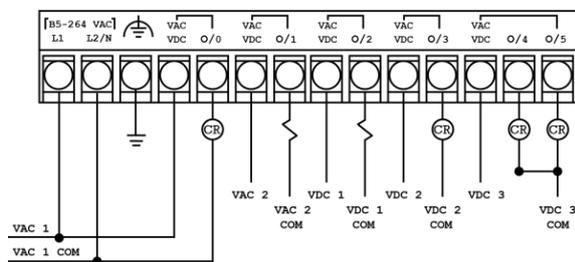


Figure 1: MicroLogix 1000 PLC output terminals

In the meantime, the input sides of the PLC treated those mapped dry contacts as sinking inputs, as shown in Figure 2.

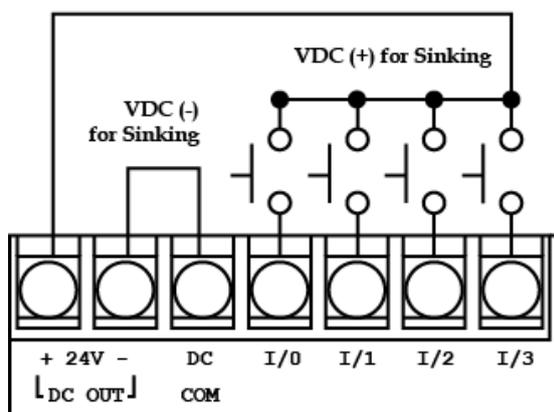


Figure 2: MicroLogix 1000 PLC input terminals

- 3). The three-tier diagram: the input and output maps graphically depict the physical wiring of the PLC but they alone are not enough to convey to a user how the PLC system operates. One more piece of information is necessary and that is the PLC program. To convey all of the information that a user needs to understand a PLC system in its entirety, we use what we have dubbed a **three-tier diagram**. As its name implies, it is composed of three elements typically arranged in such a way that it is to be read from left to right, though on more complex systems that require more information and hence more space it may be necessary to arrange the three tiers to be read from top to bottom. In the three-tier diagram, the user is shown the input module, the PLC program, and the output module. In this way, they can quickly make sense of a PLC system. As warranted, the PLC program may be accompanied by notes or a sequence of operations (SOP). A sample three-tier diagram is show below in Figure 3. Note that due to size constraints, the PLC program is not shown in its entirety but rather a simple depiction of a sample program is shown.

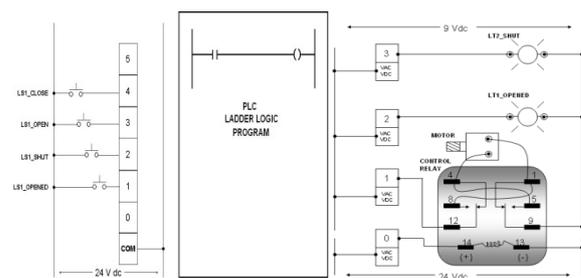


Figure 3: The three-tier diagram

- 4). Specification table: as supplementary information to accompany the aforementioned, the specification table is a useful piece of information in conveying wiring and programming to the involved personnel. The specification table is simple in construction and is composed of five data elements: the name of the field

device either a symbolic or full name; the option of that field device if applicable, the physical address of the field device if connected the PLC, the symbolic address of the field device again if connected to the PLC, and any comments which the designer wishes to express. A sample specification table is shown below in Table 1.

Table 1: The specification table showing partial field devices such as a limit switch

<i>Field device</i>	<i>Option</i>	<i>Physical address</i>	<i>Symbolic address</i>	<i>Comment</i>
Limit switch (LS) 1	Normally open (NO), momentary, 24Vdc	I:0/0	LS1	The limit switch which de-energizes the motor when the elevator has

5). Control relay: in the three-story elevator model, it allows the PLC to control the polarity of the voltage being supplied to the DC motor which drives a pinion gear along a rack to move the elevator. This directs the motor to rotate accordingly, which in turn enables for the model elevator going either up or down depending upon the desired floor the elevator is to travel.

6). Binary code: as having three normally open (NO) momentary switches for use as floor selection buttons in our scale model elevator was impractical due to physical space limitations within the model, we opted to use two floor selection buttons instead. The use of binary logic allowed us to control the elevator motion among the three floors with only two on-board selection buttons and it also allowed us to introduce binary logic to the class. The two normally open momentary switches controlled the elevator as follows.

Pressing the first floor selection button routed the elevator to the first floor; pressing the second floor selection button routed the elevator to the second floor, while pressing both floor selection buttons at once routed the elevator to the third floor.

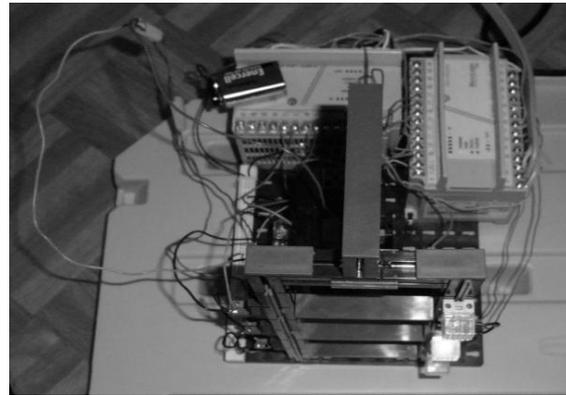


Figure 4: The scale model three-story elevator

The three-story elevator, which is discussed in greater detail in the next section, when fully constructed (in the two-PLC configuration) is shown below in Figure 4.

4. Collaborative details

As stated previously, the three-story elevator model was designed to be a fully functional representation of an actual elevator, albeit a much simpler version of its real world counterpart, for use in a classroom setting. The Model was used to instruct students with little prior PLC experience in some introductory PLC concepts. The students are tasked with the programming, wiring, and building of the model. The model elevator is used to illustrate, in hands on manner, several of the lessons that are presented to them during the course of a semester. Additionally, the level of complexity of the elevator model can be adjusted as the comprehension of the individual student(s) dictates. For example, the complexity of the required standard operating procedures can be altered so

that the model more closely mimics its real world counterpart. The scale model elevator is assembled from Fischertechnik parts and controlled by two MicroLogix 1000 PLCs. The first step in designing the model three-story elevator is to construct the specification table and prerequisite sequence of operations for the PLC system. Once this is done, both the input and output modules can be mapped out in terms of their connections to the various required input and output devices. Lastly, the PLC program can be coded collaboratively by more than one individual.

Upon completing the specification table, shown in Table 2, it becomes evident that one MicroLogix 1000 PLC lacks the required number of I/O ports to control all of the desired I/O field devices. Please note that all of the I/O field

devices are listed, however Pilot Light 3 and both of the On Board Elevator switches are not given physical addresses as there is no input port available. At this point, a decision had to be made as to whether to upgrade to a PLC with a greater number of I/O available or to redesign the entire system. In our case, we chose the latter option and decided to control the model elevator system with not one PLC but two PLCs. This would allow us to avoid the acquisition costs associated with upgrading or replacing our existing PLCs. This would also afford us the opportunity to introduce our students to a few topics of interest, one of which was a greater comprehension of how a PLC truly works.

Table 2: The specification table of the model three-story elevator

<i>Field device</i>	<i>Option</i>	<i>Physical address</i>	<i>Symbolic address</i>	<i>Comment</i>
LS2	Normally open (NO), momentary, 24Vdc	I:0/0	SF_Limit	The limit switch for the second floor
LS3	“ “	I:0/1	TF_Limit	The limit switch for the third floor
LS1	“ “	I:0/2	FF_Limit	The limit switch for the first floor
PB2	“ “	I:0/3	SF_Caller	The call button for the second floor
PB1	“ “	I:0/4	FF_Caller	The call button for the first floor
PB3	“ “	I:0/5	TF_Caller	The call button for the third floor
On Board Elevator Limit Switch 1	“ “	---	ES1	The first limit switch placed in the model elevator to mimic a floor selection button
On Board Elevator Limit Switch 2	“ “	---	ES2	The second limit switch placed in the model to mimic a floor selection button
PL1	9Vdc	O:0/1	FF_PilotLight	The first floor pilot light
PL2	“ “	O:0/2	SF_PilotLight	The second floor pilot light
PL3	“ “	---	TF_PilotLight	The third floor pilot light
MOTOR	“ “	O:0/3	MIR	Energize motor
CONTROLRELAY (CR)	24Vdc	O:0/0	MIRR	Reverse motor

Table 3: The specification table of the PLC #1

Field device	Option	Physical address	Symbolic address	Comment
LS2	NO, momentary 24Vdc	I:0/0	SF_Limit	The limit switch for the second floor
LS3	“ “	I:0/1	TF_Limit	The limit switch for the third floor
LS1	“ “	I:0/2	FF_Limit	The limit switch for the first floor
PB2	“ “	I:0/3	SF_Callr	The call button for the second floor
PB1	“ “	I:0/4	FF_Callr	The call button for the first floor
PB3	“ “	I:0/5	TF_Callr	The call button for the third floor
PL1	9Vdc	O:0/1	FF_PlotLight	The first floor pilot light
PL2	“ “	O:0/2	SF_PlotLight	The second floor pilot light
MOTOR	“ “	O:0/3	MIR	Energize motor
CONTROL RELAY (CR)	24Vdc	O:0/0	MIRR	Reverse motor

Table 4: The specification table of the PLC #2

Field device	Option	Physical address	Symbolic address	Comment
On Board Elevator Limit Switch 2	NO, momentary 24Vdc	I:0/0	ES2	The second limit switch placed in the model to mimic a floor selection button
LS3	“ “	I:0/1	TF_Limit	The limit switch for the third floor.
On Board Elevator Limit Switch 1	“ “	I:0/2	ES1	The first limit switch placed in the model elevator to mimic a floor selection button.
#1 Triggers the 1st PLC	24Vdc	O:0/0	CBM1	Triggers PLC #1 to send the elevator to floor 1
#2 Triggers the 1st PLC	“ “	O:0/1	CBM2	Triggers PLC #1 to send the elevator to floor 2
PL3	9Vdc	O:0/2	TF_PlotLight	The Third floor pilot light
#3 Triggers the 1st PLC	9Vdc	O:0/3	CBM3	Triggers PLC #1 to send the elevator to floor 3.

After the decision was made to use two PLCs rather than one, the original specification table shown in Table 2 was revised to account for the addition of another PLC into the system. The two PLCs will henceforth be referred to as PLC #1 and PLC #2. Their specification tables are shown in Tables 3 and 4, respectively. Please note that the sequence of operations (SOP) for the system remained unchanged.

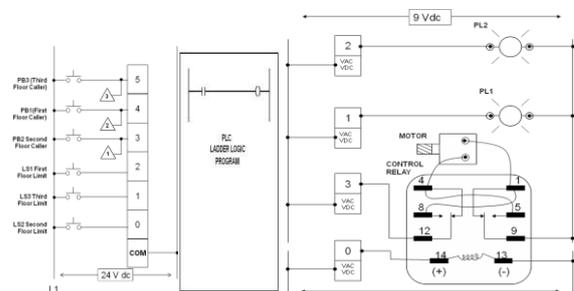


Figure 4: The three tier diagram for PLC #1

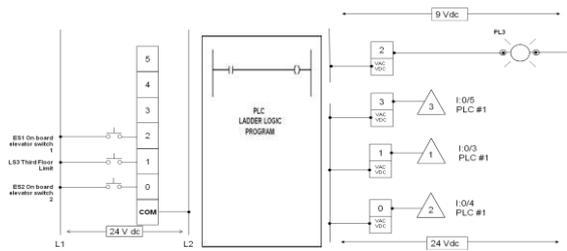


Figure 5: The three tier diagram for PLC #2

Following the completion of the specification tables, the two three-tier diagrams were constructed, one for each PLC in the system, as shown in Figures 4 and 5, respectively. The PLC programs for both PLC #1 and PLC #2 are excluded to keep the space lean.

In this configuration, PLC #1 controls the motion elevator completely while PLC #2 processes the inputs from the on board elevator switches and in turn relays that information to PLC #1 so that it can execute the instruction accordingly. For example if “on board elevator switch #1” is pressed; PLC #2 will energize its output “Call Button Mimic #1” which is connected to PLC #1s “First Floor Caller”. PLC #1 interprets this in the same way as if the first floor caller button was actually pressed and it dispatches the elevator accordingly. When both onboard elevator switches are pressed, PLC #1 dispatches the elevator to the third floor. In this way we can execute the desired sequence of operations.

5. Conclusions

In this paper, an advantageous engineering approach is proposed for developing a PLC learning platform for collaborative programming and configuration activities. Two PLC units were synchronized to control one PLC-driven system. Our work in collaborative programming began when

we first sought ways to push the MicroLogix 1000 PLC beyond its limited number of inputs and outputs. To accomplish this, we used two PLCs that were connected together. One PLC’s outputs were connected to the other PLC’s inputs so that the two PLCs could communicate. This communication of sorts allowed us to model a system that would have been otherwise beyond our capabilities without a PLC upgrade. Now this is not to say that this is the only way this problem could have been solved. It is, however, not only a valid, but also an affordable solution.

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