Programmable Logic Controllers

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INTRODUCTION

Technology is a central part of our modern society, and automated manufacturing systems are essential to our technology. Without the ability to quickly and reliably manufacture materials and equipment, the widespread availability of objects from smartphones to furniture would not be possible.

At the heart of modern manufacturing systems are the controllers that direct the machines, track the parts, and perform quality control. For most manufacturers today, this controller is a programmable logic controller (PLC). PLC's are powerful, robust, and versatile controllers designed especially for manufacturing applications – so powerful and stable, in fact, that they have often found a home outside of manufacturing, in systems where reliability is paramount. However, despite their importance to modern society, PLC's remain largely hidden from view.

This article provides a brief overview of PLC's, including their history, construction, and configuration. Like most technology, PLC's are also undergoing a period of progressive change, and so this article closes with a discussion of future trends in PLC technology.

BACKGROUND

Machines have existed in various forms for thousands of years. Simple machines such as levers or wheels stretch back to time immemorial, while more sophisticated machines, such as catapults or water-driven mills, are contemporary to civilization (James & Thorpe, 1994). With the Industrial Revolution, the combination of higher quality materials for machine construction and improved power sources (such as the steam engine) changed the nature of manufacturing. Very rapidly, manufacturing processes shifted from artisan construction to machine-assisted manufacturing (Lane, 1978).

Despite the advantages provided by these new machines, the lack of automatic control systems remained a significant barrier. Where an artisan once made the product directly by hand, his labor was now employed in constantly managing the machine that made the product. Industrialists noted that if machines could somehow manage themselves, manufacturing would be more efficient, uptime would be increased, and human labor could be shifted to more value-added activities. Inventors began exploring possibilities for automatic regulation, starting with mechanical systems, such as the centrifugal governor, and expanding into other methods, such as thermal, hydraulic, or pneumatic systems (Bennett, 1996).

In the 19th and 20th Centuries, electrical engineering and technology had become sufficiently mature that electrically-based systems were a preferred technology for controlling manufacturing equipment (Bennett, 1996). The core of these controls systems was the electro-mechanical relay, or simply "relay." In it's first stage (called a "coil"), this device uses the current from an electrical signal to generate a magnetic field. This magnetic field then causes a mechanical switch to complete another electrical circuit (the "contact") in the second stage (Gurevich, 2006). To disconnect the contact, the first stage is deactivated and a spring returns the contact to a resting state. The relay is important because its design performs two important functions. First, it electrically isolates the activating signal from the output signal, allowing information to be reproduced without loss and with potentially different electrical properties (voltage, current, or power levels). Second, it provides a method for controlling a circuit based on the behavior of not just one, but multiple components connected to the coil. Different connections create different behavior, including logical functions.

This final feature creates the potential to add not only control (on/off activation) but logic (control coordinated with other elements of the system) to the functioning of a machine. Very rapidly, machine designers began

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using "relay logic," or interconnected relays emulating logical functions, to control their machines (Wakerly, 2001). Banks of relays were installed on metal sheets called "backplanes" and mounted within metal enclosures called "cabinets." These cabinets both protected the array of delicate relays from harsh manufacturing environments, and protected users from the relays' electrical energy.

Despite their advantages, many challenges arose from using relays to control machinery. First, relays have mechanical parts which eventually fail after extensive use. This could either be a minor or major inconvenience based on the logic and application. Second, a significant amount of wiring was required to connect the relays in the desired manner. Wires also fail, and tracing the source of a failure was a daunting task for even simple systems, potentially causing significant downtime. The logic itself had little flexibility; if an error was discovered, correcting it required a significant and time-consuming rewiring. Finally, if new equipment required a logic change, users had to choose between either rewiring their existing systems (time-intensive and error-prone) or replace the existing cabinets with new ones (faster, but very expensive) (Erickson, 1996).

After the invention of the transistor in 1968, controllers became available that both miniaturized the functionality of relay logic and used only a small fraction of the power required by relays. Coincident with this, General Motors Hydra-matic division, which regularly needed to upgrade large and sophisticated control systems, developed a specification for a "standard machine controller," the first functional description of a PLC. Bedford Associates won the contract for developing this device and, in 1969, the Bedford Associates 084 became the world's first PLC (Erickson, 1996). Since then, many other companies, such as Allen Bradley, Siemens, Mitsubishi, and GE, have developed and manufactured PLC's, releasing new models as the state of computing technology has progressed.

LITERATURE REVIEW

Since PLC's have become foundational devices in industrial control systems, modern research has focused on two key areas: successful application of PLC's in challenging or complex systems, and expanding the design range of modern control systems.

Researchers have successfully integrated PLC's into a wide range of systems, including energy management (MacKinnon, Warnick, & McDaniel, 2011), wheelset disassembly (Jun & Wen, 2010), powder-compacting presses (Sowmiya, 2013), and fire suppression systems for hydroelectric power stations (Lei-hua, Wei-hua, & Feng, 2009). As system complexity has grown, practicioners have sought automated techniques for thoroughly validating the operation of PLC code, such as using simulated manufacturing facilities (Park, Park, Wang, Kwak, & Yeo, 2008), BIP (Behavior, Interaction, Priority) frameworks (Wang, Guan, Luo, Zhang, & Song, 2013), and sensor graphs (Alenljung & Lennartson, 2009).

While PLC's are the most common control platform in industrial applications, they are not the only control solution in use. Some researchers are exploring the integration of PLC's with embedded systems to benefit from advantages of both architectures (Zhang, Liu, Tang, & Xu, 2010). Distributed control systems (DCS) offer another alternative, structuring the automation system so that multiple intelligent controllers interact to produce system behavior (Dai, Vyatkin, & Christensen, 2013).

Some researchers are also exploring alternative programming strategies for PLC's, including artificial intelligence techniques such as neural networks (Topalova & Tzokev, 2010), fuzzy logic systems (Xiangde & Lishun, 2012), or genetic algorithms (Dadone & Vanlandingham, 1999). These techniques enable PLC's to function effectively even when presented with noisy or partial information.

PLCS: THEIR DESIGN AND APPLICATION

PLC Architecture

While modern PLC's are available with a wide range of colors, form factors, and electrical properties, their overall architectures remain very similar.

The most basic PLC's are single, all-in-one devices that contain just a central processing unit (CPU) and a set of input and output ("I/O") ports to which other devices can be electrically connected. Wires are connected to the I/O ports at "terminals." The two most common terminal types are screw terminals, where a