11

Control Technology and Automation

Basic Concepts

- List some impacts of control technology and automation on society.
- Explain open loop and closed loop feedback in control circuitry.
- Describe different levels of control technology.
- Discuss the history of control technology.
- Identify applications of control logic.
- Define OR, AND, and NOT logic.

Intermediate Concepts

- Describe how sensors provide feedback in closed loop control circuits.
- Explain the advantages of computer or programmable control over other methods of control technology.
- Read values expressed in the binary-coded decimal (BCD) system.
- Use line diagrams and control logic to design basic control circuitry.
- Identify the functions of NOR and NAND logic in control circuits.

Advanced Concepts

- Demonstrate the use of five forms of control logic in control circuitry.
- Design and construct control circuitry for specific applications.

Control technology and automation are everywhere in our daily lives. Not only are control technology and automation at the heart of modern industry, but they have also made their way into most other areas of society. Automation is now a common feature in the home. Think about the many sensors that control things in your house. A thermostat controls the air temperature automatically, operating the furnace or air conditioner without any human intervention. Another thermostat automatically keeps the temperature inside your refrigerator cold enough to prevent food from spoiling. Floodlights outside your home may turn on as your car pulls into the driveway and activates a motion sensor. Timers, electronic eyes that sense darkness, or even sensors that detect heat may control lights.

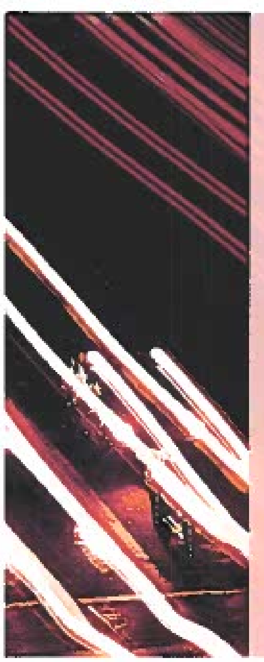
Other devices around the home use more complex control systems. For instance, a washing machine has a control system that takes it through a number of steps. The system must start the water flowing, adjust the water temperature, sense when the machine's tub is full of water, run the agitator in different directions and for varying lengths of time, drain the water from the machine, and spin excess water out of the clothing. To do these tasks, the control system uses a series of automated valves, a timing mechanism, and various sensors.

All control systems have input and output devices. Additionally, all control systems make decisions. With simple control circuits, the decisions are often made by the way the input devices are arranged in the circuit. For example, assume you have a heater that is to be controlled automatically by a thermostat. The simple control circuit would look like the one in **Figure 11-1.** What if the heater is located, however, in your basement, which you do not use very often? You want the heater to operate only when you are using the basement. You can add a master switch to the circuit, so the thermostat can function only if the master switch is "on." The revised circuit is shown in **Figure 11-2.**

What Is a Control System?

A control system is a group of components working together to produce desired results. It does this by monitoring inputs and regulating outputs. **Figure 11-3** shows the most basic control system elements.

Career Connection



Electrical Engineering Technicians

Manufacturing

The use of control systems is dependent on technology. People rely on their thermostats and motion detectors. It is important for these technological systems to function properly for continued use. Part of the job of an electrical engineering technician is to install and repair control systems.

Electrical engineering technicians maintain the electrical circuitry used in control systems. They study the work of engineers and make changes to designs where necessary. These technicians assist engineers throughout the design, assembly, and testing processes. They evaluate data received through testing, in order to fix any developmental problems. Electrical engineering technicians have the authority to recommend approval for electrical engineering projects. They are also responsible for ensuring safety in designs.

These technicians must have a thorough background in engineering. Their knowledge must include design and electronics principles. Also, since their duties may include language-oriented tasks, such as reviewing proposals, they must have well-developed written communication skills. An Associate Degree is required for this position. The yearly salary may range from $29,000 to $79,000.

Figure 11-1. A simple heater circuit with a temperature-controlled switch (thermostat).

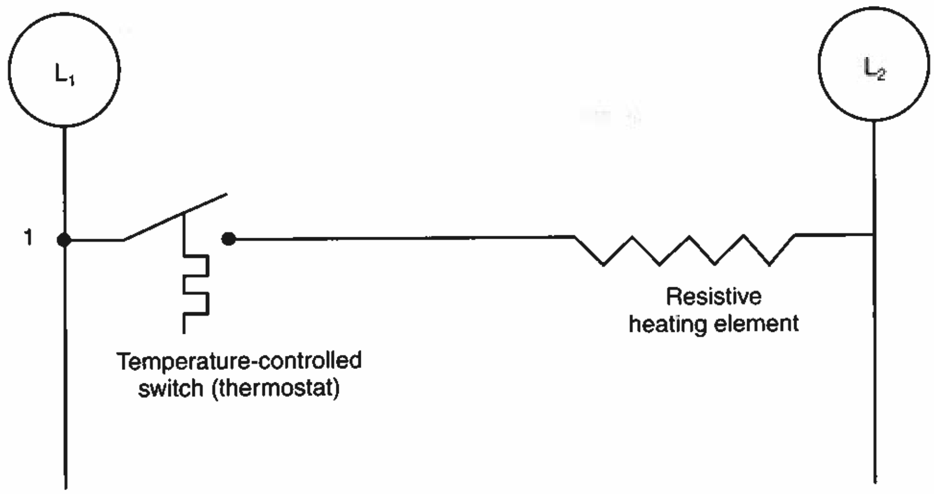


Figure 11-2. A simple heater circuit with thermostatic control and a master switch. The thermostat can control the heater only if the master switch is closed.

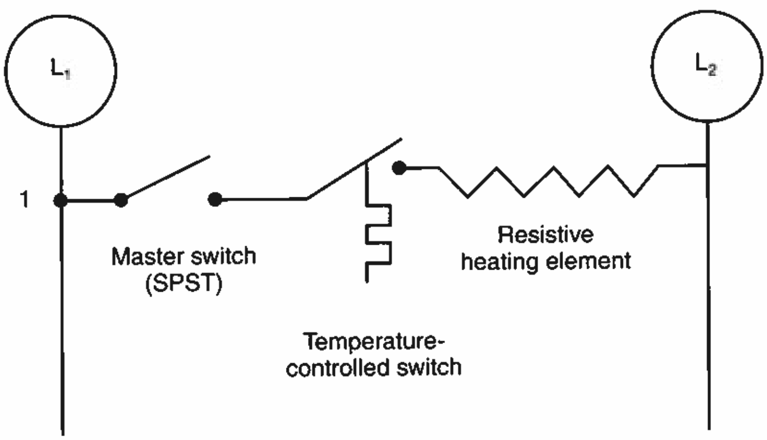
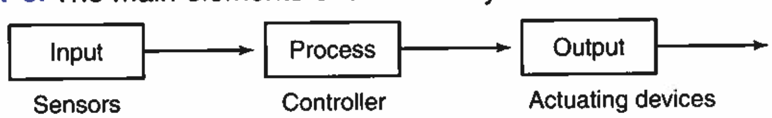


Figure 11-3. The main elements of a control system.



They are input from sensors, processing through a controller, and output of the results using some form of actuating device (such as a lamp, horn, or motor).

Understanding Line Diagrams

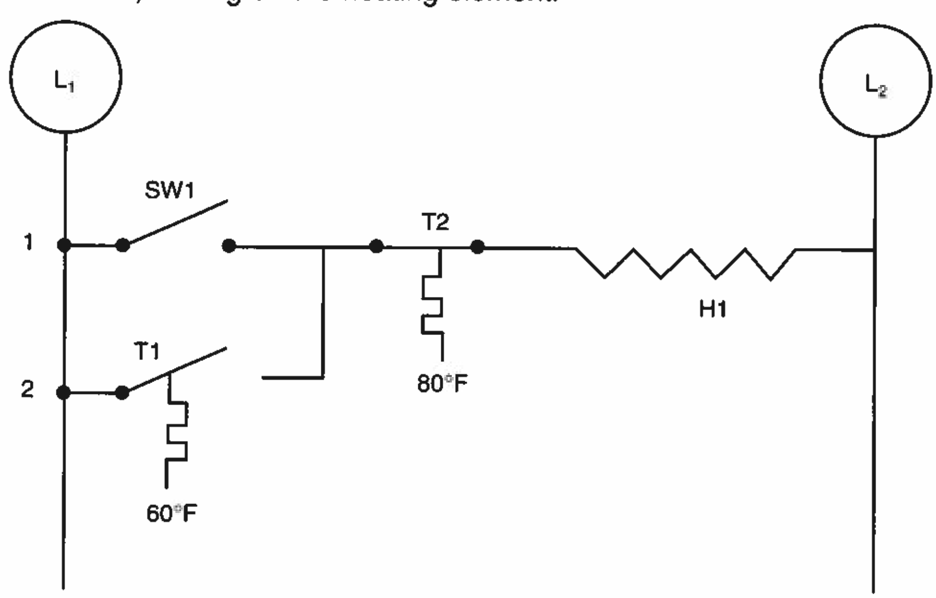
Line diagram: A pictorial representation of a control circuit.

The control circuits in Figure 11-1 and Figure 11-2 are shown in the form of ***line diagrams***. Such diagrams are often referred to as *ladder diagrams* because of their appearance. Line diagrams are pictorial representations of control circuits. They are the key to understanding and creating control circuitry. When you read or create line diagrams, keep these simple rules in mind:

- Read all line diagrams from top to bottom and left to right.
- The rails of the ladder (L_1 and L_2) represent the power for the control circuit (usually 12 V, 24 V, 110 V, or 220 V). If the control circuit has a hot leg and a neutral or cold leg, the hot leg is assumed to be the left hand rail of the ladder (L_1). The hot leg may be labeled + for positive, and the neutral leg (L_2) may be labeled – for negative.
- All inputs (switches and sensors) are shown to the left of the output to be controlled.
- There can be any number of inputs on a line, but only one output per line is allowed. That output should be connected to L_2.
- Lines are typically numbered so they can be referenced.

Figure 11-4 is a simple line diagram for a heating element control circuit. Note that the heating element can be controlled manually with the use of a toggle switch (SW1) in line 1, or it can be controlled automatically by the temperature switch (T1) in line 2. Switch T1 closes on falling temperature and will energize the heating element (H1) when the temperature drops to 60°F. If the heater has already been energized manually with switch SW1, switch T1 is bypassed. Note the switch in Line 1 labeled T2. This is the high-temperature cutoff switch, which will open when the room temperature reaches 80°F, turning off the heater.

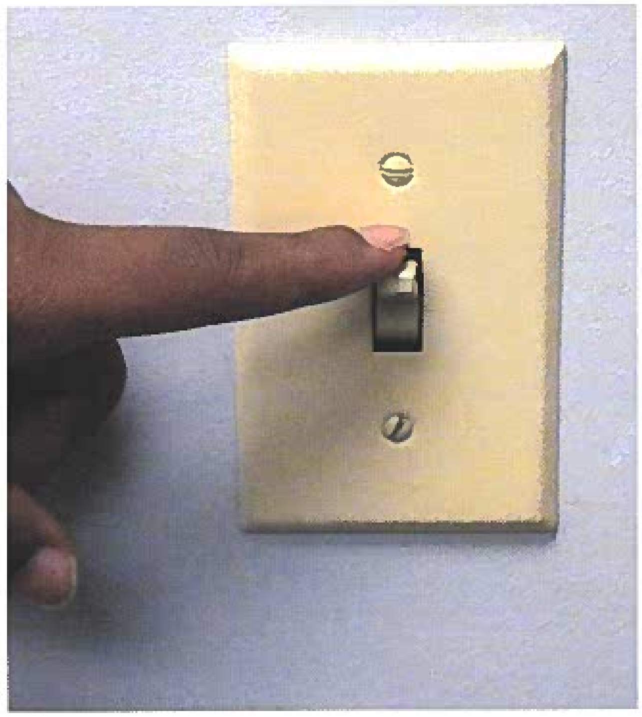
Figure 11-4. This line diagram shows a heating element that can be controlled manually by closing SW1 or automatically by the normally open thermostat T1, which closes when the room temperature drops to 60°F. Thermostatic switch T2 is normally closed, but it will open if the temperature reaches 80°F, turning off the heating element.

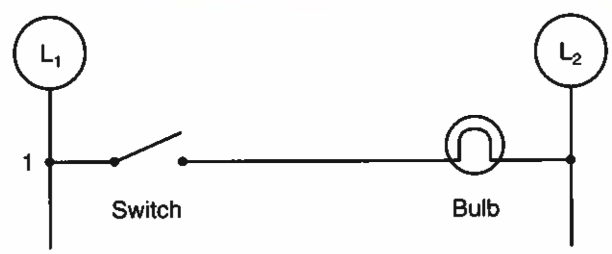


Open Loop Control Circuitry

There are two basic types of control circuits, open loop and closed loop. In an ***open loop system***, the system output has no effect on the control (input). For example, when you operate a light switch, the room light may or may not come on. See **Figure 11-5.** The electrical circuitry has no way of checking to determine if the lightbulb is burned out or is operating properly. There is no feedback mechanism built into the system to identify the state of the bulb.

Figure 11-5. A light switch is an example of an open loop control system. There is no feedback to indicate whether the lamp did or did not turn on.

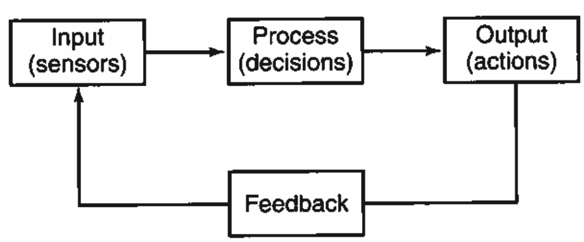




Closed Loop Control Circuitry

Some control systems can consider the output of a system and make adjustments based on that output. They use information provided by sensors, called *feedback*, to predict the best way to control a process. This type of control is referred to as a ***closed loop system***. See **Figure 11-6.** For example, the thermostat in a water heater turns on the heating element when the water temperature in the tank drops to a predetermined level (the low ***set point***). The heating element will stay on until the temperature reaches the *high* set point, when the thermostat will turn it off.

Figure 11-6. Closed loop control systems make use of sensor information (called feedback) to make any necessary adjustments in processing.



Basic Control Elements

To understand control technology and automation, you must be familiar with basic electricity, fluid power, and mechanics, along with their corresponding control elements. These control elements include transmission devices, storage devices, protection devices, motion control devices, and advantage-gaining devices. Without the use of these devices, control and automation circuitry simply could not function. See **Figure 11-7.**

Levels of Control Technology

There are four different levels of control technology. See **Figure 11-8.** Each level builds on the previous one.

The first and simplest type of control technology is referred to as ***manual control***. Manual control requires human input in order to function. Pressing the start button of your microwave, opening a faucet, or turning the ignition key of your car are all examples of this type of control.

Figure 11-7. Basic power control devices for the various forms of power.

Forms of Power			
	Electrical	**Fluid**	**Mechanical**
Transmission Devices	Wires Cables Buss bar	Hoses Pipe Tubes	Shafts Rods Belts
Storage Devices	Batteries Capacitors	Pressure tanks Accumulators	Springs Flywheels
Protection Devices			
Effort	Surge suppressors Breakers	Pressure relief valves	Shear pins, keys Torque limiting clutches
Rate	Fuses, circuit breakers	Velocity fuses	Governing mechanisms
Advantage-Gaining Devices	Transformers	Flow amplifiers	Gears, levers, pulleys Other simple machines
Motion Control Devices			
On/Off	Switches	Spool valves	Sprague clutches
One-way	Diodes	Check valves	Overrunning clutches
Variable	Potentiometers	Variable flow restrictors	Frictional clutches

The second level of control technology is ***automatic control***. As the name implies, automatic control is achieved by using a sensor or another automatically functioning device, such as a timer, to turn a machine on or off. This eliminates or reduces the need for input from humans. An electric eye that turns on lights when it becomes dark outside and a sensor that prevents a car from being placed in gear unless the driver's foot is on the brake pedal are examples of automatic control.

The third level of control technology is ***programmable control***. This level of control typically uses a dedicated microprocessor or computer as the brains of the system. ***Programmable logic controllers (PLCs)*** are microcomputers designed exclusively for control purposes. As such, they offer several distinct advantages for control technology over the desktop microcomputers with which we are all familiar. A desktop microcomputer is versatile and can perform many different kinds of tasks. A PLC, however, is designed to do *one thing* well: receive signals (inputs), process those inputs based on the program, and provide outputs. Since PLCs were developed to operate in industrial environments, they are less subject than microcomputers to interference from noise, vibration, or humidity. A very important feature of the PLC is the programming method. Programming is done in a line-by-line format, similar to the line or ladder diagrams familiar to electricians and control technicians. For this reason, the PLC is regarded as easier to program than a microcomputer, which may require knowledge of a complicated programming language.

Regardless of whether a microcomputer or a PLC is used, one characteristic makes programmable control stand out from lower levels of control technology: the control functions or instructions can be easily modified. For example, you can program the operating sequence of a

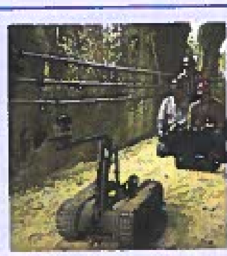
Open loop system: A control circuit in which the system output has no effect on the control.

Closed loop system: A control system that considers the output of a system and makes adjustments based on that output.

Set point: A predetermined output level at which a closed loop system makes an adjustment.

Manual control: The simplest type of control technology, requiring human input in order to function.

Figure 11-8. The four levels of control technology.

Levels of Control		
	Type	**Description**
	Manual	Human as controller.
	Automatic	Machine is self-acting or self-regulating.
	Programmable	Control instructions easily changed by humans.
	Intelligent	Machine emulates human abilities to solve problems and assign meaning.

traffic light using a PLC or microcomputer. The program would cycle through the red light/yellow light/green light sequence and then begin the process again. Once the traffic light is installed, it would be easy to modify the program to make the light behave differently. You might want a longer yellow light or decide that only a blinker was necessary late at night. Using a programmable device, you could easily make these things happen without ever touching the hardware used to construct the traffic light. You would do this by simply changing the program in the computer. This powerful concept of easily modified instruction makes modern automation possible.

The highest level of control technology is known as ***intelligent control.*** This form of control uses machines and programming techniques that are capable of solving complex problems without human intervention. The technology emulates human thought processes using sophisticated software that makes use of artificial intelligence principles.

Automatic control: The level of control technology achieved by using a sensor and another automatically functioning device, such as a timer, to turn a machine on or off.

Programmable control: The level of control technology that typically uses a dedicated microprocessor or computer as the brains of the system.

Programmable logic controller (PLC): A microcomputer designed exclusively for control purposes.

Intelligent control: The highest level of control technology. It uses machines and programming techniques capable of solving complex problems without human intervention. The technology emulates human thought processes using sophisticated software that makes use of artificial intelligence principles.

Technology Link

Medicine: Intoxilyzers

Complicated sensors are most commonly associated with industrial applications. There are many other applications for automated sensors, however, that have nothing to do with industrial control. These sensors are used for other types of important applications. One such application is to perform a sobriety test.

An intoxilyzer is one type of detection device that can determine a person's blood-alcohol level. Generically, these devices are usually referred to as *breathalyzers,* but a true breathalyzer uses a chemical reaction to determine blood-alcohol level. An intoxilyzer measures blood-alcohol level with infrared (IR) spectroscopy. This process identifies the level of alcohol in the blood by passing an IR beam of light through a sample chamber that a person breathes into. On the opposite side of the sample chamber is a filter wheel that measures certain variations in the wavelength of the IR beam. The variations are created by the effect that alcohol has on the IR beam of light. More alcohol creates greater variations. The wavelengths are then converted to electrical impulses that are sent to a microcomputer for interpretation. Ultimately, a blood-alcohol level reading is digitally displayed.

A Brief History of Control Technology

Manual control is the oldest and most widely used form of control technology. It was in use long before the development of sensors and programmable control devices. It would be a mistake, however, to assume that all manual control circuits are simple—they can become quite complex. Modern control circuits that use sensors and programmable control devices are often based on knowledge of manual control circuitry. Thoroughly understanding manual control circuitry is essential to working with the more advanced levels of control technology.

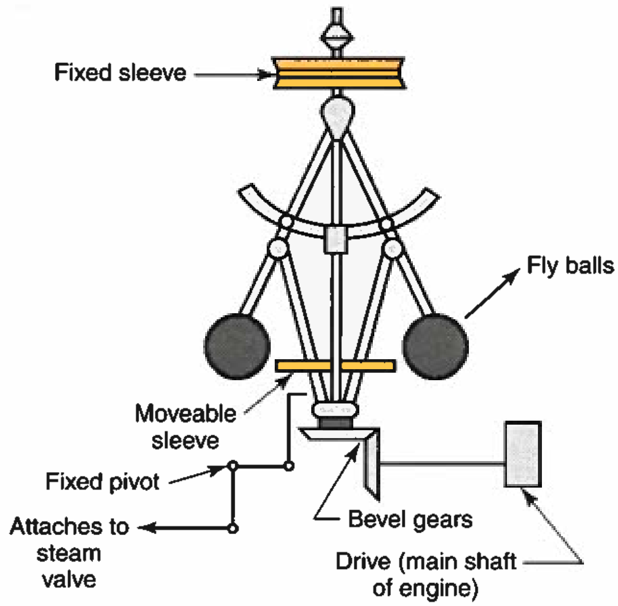
STEM Connection

Technology: Intelligent Control

Researchers are making progress in developing machines that are not only reprogrammable, but that can learn while executing instructions—in some cases, correcting their own programs. This important new form of control technology is referred to as *intelligent control.* All control systems emulate the human thought process in some way. A control system that can solve problems and assign meaning to complex inputs is an intelligent control system. The point at which true artificial intelligence starts and ends, however, is not easily identified. After all, even an expert system capable of making complex decisions was created by a human being.

It is also important to note that not all forms of automatic control technology rely on electronic sensors or the microchip. For instance, James Watt's fly ball governor is an early example of automatic control that represented a real technological breakthrough. The governor functions automatically, but it is totally mechanical. Before Watt developed the fly ball governor in 1788, steam engines had to be controlled manually, a particularly difficult and dangerous task. The governor allowed the steam engine to feed itself with more steam automatically, while producing a relatively constant amount of power from the engine. The main shaft of the engine turns the governor. See **Figure 11-9.** As the engine speeds up, centrifugal force causes the fly balls (weights) to move away from the axis of rotation. This outward movement closes the steam valve, slowing down the engine. Decreased centrifugal force, coupled with gravity, then causes the weights to pull back toward the axis of rotation, opening the steam valve and starting the closed loop cycle all over again.

Figure 11-9. Watt's fly ball governor is an example of a totally mechanical automatic control. Although this mechanism was invented more than 200 years ago, it is still in use today for various types of engine control applications.



Programmable control is most closely associated with the development of the microchip and the microcomputer. Early forms of programmable control, however, used mechanical methods. One of the most important systems of programmable control was the punch card developed in the early 1800s by Joseph-Marie Jacquard, a French weaver. He automated the weaving of complex patterns by using different patterns of holes, punched in a series of cards, to control operation of the weaving loom. The cards were strung together to form a loop that automatically produced the same pattern over and over. See **Figure 11-10.** To produce a different pattern, another set of punched cards was mounted on the loom. The idea of punch card control was used in early computers and in industrial machinery control through the first half of the twentieth century.

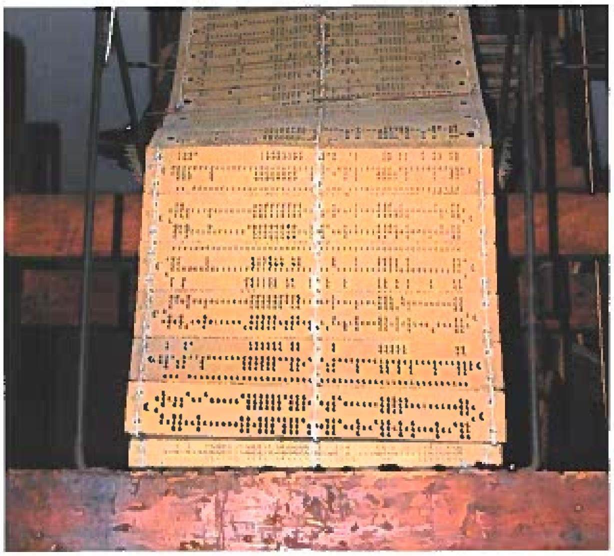
From the early days of the computer, it was understood that one of the best applications for the device would be for industrial control purposes. Prior to computer control, heavy manufacturing industries, such as the automotive industry, had to totally reconstruct assembly lines whenever their products changed. The computer offered the power to simply modify programs and have the machines along the assembly line react differently. See **Figure 11-11.** General Motors pioneered the use of PLCs in the automotive industry, installing its first unit on an assembly line in 1968. Early PLCs were very large and very costly, but they could replace up to 100 relays and eliminate the need for scores of timers and counters along the assembly line. Modern PLCs are smaller and less expensive. Today, if a PLC can take the place of several timers or counters, it is less costly to use the PLC than the stand-alone components.

GREEN TECH

In automated machining, a cutting fluid, or machining coolant, is sprayed onto the workpiece as it is cut. Used coolant can be maintained. Because of the possible environmental impacts, it is unlawful to dispose of coolant without using approved containers and following certain protocols.

Figure 11-10. An early form of programmable control that predates the computer by hundreds of years is the Jacquard punch card system. It was used to control a loom weaving textiles with complex patterns. A—The punched cards were strung together to run through the loom, with the hole patterns governing which threads were woven into the design. B—Textiles with very complicated patterns could be consistently reproduced with the Jacquard method. To change patterns, a different set of punched cards was mounted on the loom.

A



B

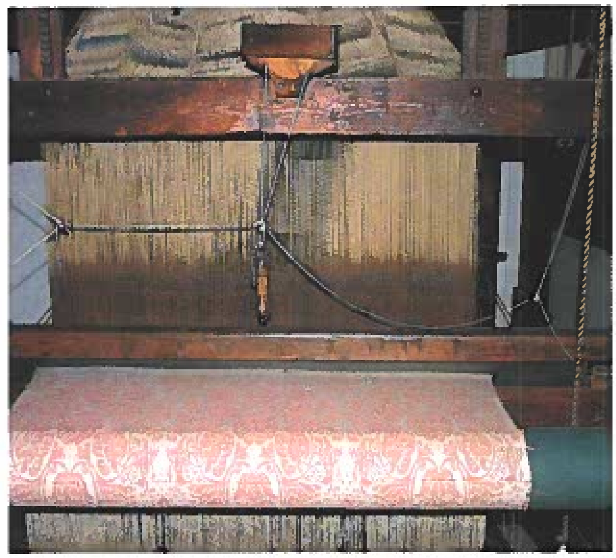
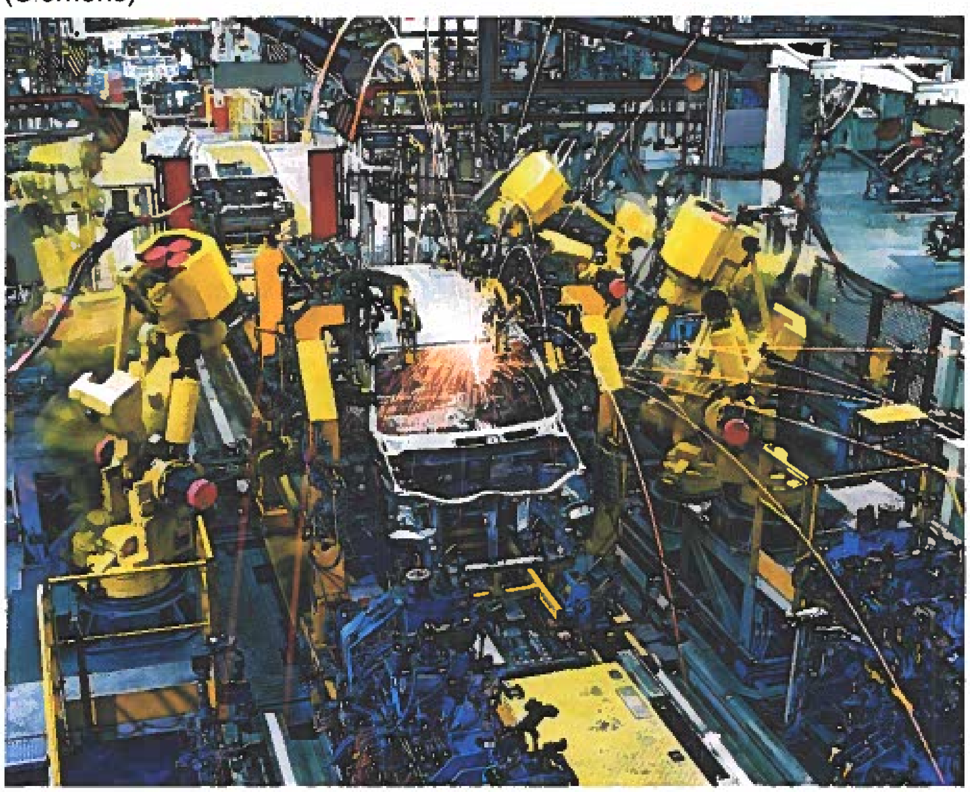


Figure 11-11. Modern programmable control is most closely associated with the microcomputer and the microchip. A computer is controlling these welding robots on an automotive assembly line. The computer can be easily reprogrammed to adapt the robots to produce a different size or type of vehicle. (Siemens)



Inputs, Processes, and Outputs

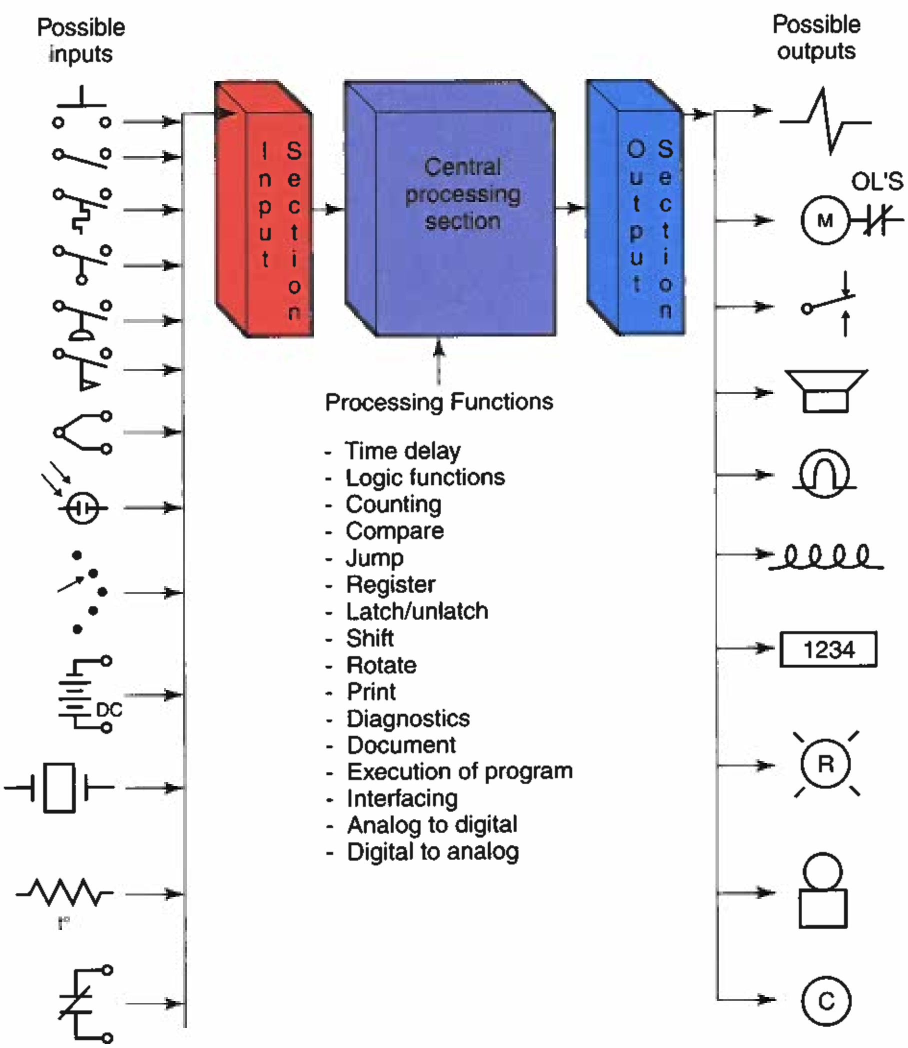
Programmable control systems are based on a computer or PLC that receives signals from external sensors (input), performs processing functions on those signals, and then sends a signal (output) to some form of actuating device. **Figure 11-12** is a schematic representation of such a system, showing examples of inputs and outputs, as well as listing typical processing functions.

Inputs

Input devices allow the computer or PLC to receive signals from external sensors, such as touch, temperature, light, or rotation sensors. There are two primary types of input signals. The first and easiest type to understand is a ***digital signal***, which has only two possible states—the sensor either sends a signal or does not send a signal. Examples are a switch (on or off) and a thermostat designed to turn something on or off

Digital signal: An input signal that has only two possible states—the sensor either sends a signal or does not send a signal.

Figure 11-12. This diagram of a programmable logic controller (PLC) shows typical processing functions and examples of input and output devices that can be attached to the PLC to form control systems.



at a specific temperature. When a switch is moved to "on" or a sensor reaches its set point, a positive signal is sent to the processor. This signal is often referred to as a ***true signal***, or *high signal*. If the switch remains in the "off" position or the thermostat does not reach its set point, no signal is being sent. This is often referred to as a ***false signal***, or *low signal*.

True signal: A positive signal sent to the processor when a switch is moved to "on" or a sensor reaches its set point. Also referred to as a high signal.

False signal: No signal being sent, such as when a switch remains in the "off" position or a thermostat does not reach its set point. Also referred to as a low signal.

The second type of input signal that can be sent is an ***analog signal***. Analog signals are used to transmit variable data, such as percentage of light, loudness of a sound, or weight of an object. In such cases, the data being transmitted can vary greatly within a given range. A simple true/false signal is not useful, since it does not supply enough information to the controller. Since computers are devices that understand only digital signals, the analog data must first be converted into digital form. This conversion can be accomplished in various ways. One way is to vary the voltage or current returned to the controller from the sensor. The computer or PLC can then interpret the voltage or current variations as representing particular values. Industrial control devices work this way, using ***analog-to-digital converters (A/D converters)*** for signal processing. A/D converters are electronic circuits that convert the analog information sent from sensors to digital representations the computer can understand.

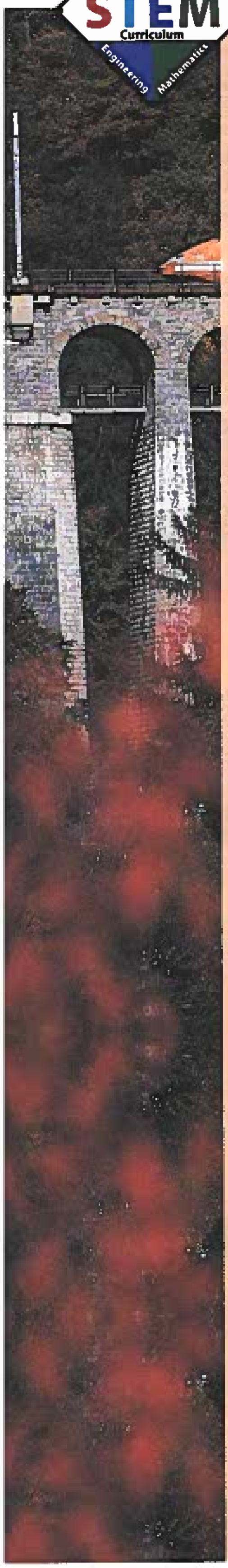
Analog signal: An input signal used to transmit variable data, such as percentage of light, loudness of a sound, or weight of an object.

Analog-to-digital converter (A/D converter): An electronic circuit that converts the analog information sent from sensors to digital representations a computer can understand.

A more cumbersome conversion method is to use multiple input ports to represent a digital value in the ***binary-coded decimal (BCD)*** numbering system. This system represents values using only the digits 0 and 1 (*false* and *true*). Assume a process was to occur six times. Signals at the four input ports would read *0110*, or *false/true/true/false*. In the BCD system, *0110* represents the number *6*. In this way, a variable (analog) value can be represented digitally, without the use of an A/D converter. The tradeoff is that BCD inputs require multiple input ports. Using four input ports, the range of numbers that can be represented is only from *0* to *15*.

Binary-coded decimal (BCD): A numbering system that represents values using only the digits 0 and 1 (*false* and *true*).

Sensors are also important because they provide feedback for control purposes. Feedback often represents the difference between something that is accurately controlled and something that is controlled more crudely. For example, imagine that you have a greenhouse you want to keep cool in the summer. You could create a simple circuit to turn a fan on all day and switch it off at night, but this could prove wasteful and inefficient. Similarly, you could use slightly more complex circuitry to turn the fan on and off at set times throughout the day, but this too could prove less than ideal. What if it was a cool day? The fan would continue to cycle on and off anyway. Both of the previous examples represent open loop control technology. No feedback has been employed to control the fan. It simply turns on and off, without regard to the environment. A more accurate and efficient control method would be based on the temperature within the greenhouse, and this is where sensory technology and feedback come into play. The feedback from a temperature sensor represents closed loop control technology. The actual greenhouse temperature determines when the fan turns on and off. With the use of feedback and closed loop control technology, it will be much easier to keep the greenhouse within the desired temperature range.



STEM Connection

Math: Counting in Binary-Coded Decimal (BCD)

Beginning in kindergarten, you learned our conventional (Base 10) system of counting. You also have been exposed to other numbering systems, such as the Roman numeral system. What does IX stand for in the Roman numeral system? If you said it means *9*, you are correct. Like the Roman numeral system, the binary-coded decimal (BCD) system is simply another way of counting. The BCD system allows analog information—such as temperature variations, rotation speeds, humidity levels, or pressures—to be converted into digital information. To do so, the BCD system allows for the conversion of any number into a series of *0*s and *1*s. BCD values are read from right to left. The place values in BCD, from right to left, are 1, 2, 4, 8, 16, 32, and so on. See **Figure 11-A.** The actual digit shown in each place, however, is either *0* or *1*—a *0* literally means 0, but a *1* indicates a value equal to its place in the sequence.

Try counting in BCD. Read the following number from right to left: 01001. What number does this sequence represent? If you said the number *9*, you are correct. How was this determined? The first number on the right indicates a *1*. The second and third numbers would represent *2* and *4*, if *1*s were present. Since they are both *0*s, however, they represent *0*. The fourth digit has a *1* present, which represents an *8*. The fifth digit (that could represent *16)* is a *0*. So adding 1 + 8, you get the number *9*.

Can you see the value of BCD when it comes to inputting information into a computer or programmable logic controller (PLC) that relies on digital information? It would take only five digits to represent a numerical value up to *31*, six digits to represent a numerical value up to *63*, and only seven digits to represent a value up to *131*. The PLC can be programmed to interpret digital inputs in BCD. If it could not, can you guess how many inputs would be required to represent the number *131*? You probably guessed right: it would require 131 inputs. Because of the BCD numbering system, however, we can represent any number between *0* and *131* with only seven input ports.

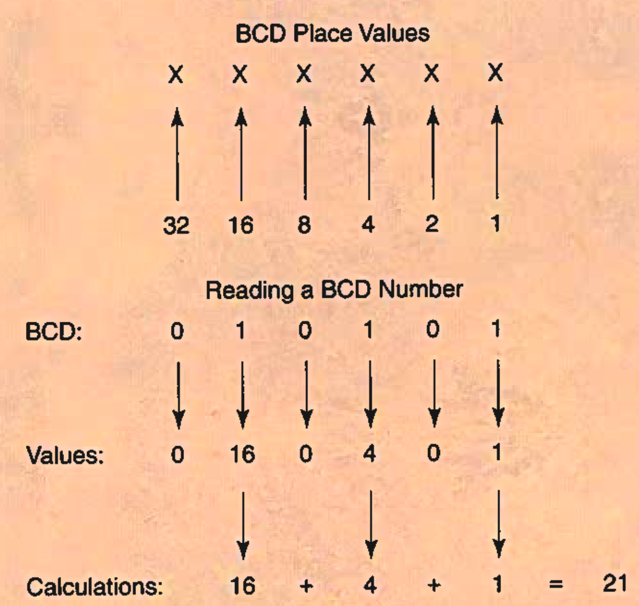
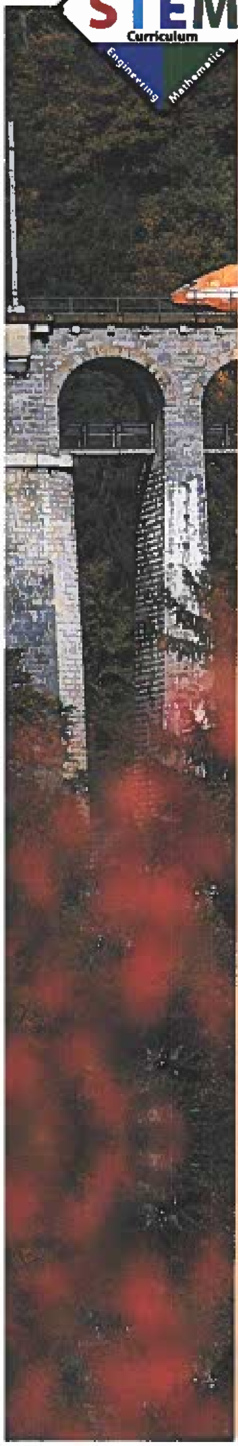


Figure 11-A. Binary-coded decimal (BCD) place values determine how a number is read.



STEM Connection

Technology: Smart Sensors

Most switches and sensors operate in a way that is fairly easy to understand. Push a switch, and the contacts on the switch open or close to create a desired effect. The functioning of some sensors, such as electric eyes, motion detectors, and proximity sensors, however, is more difficult to comprehend. Here is a quick look at how one of those smart sensors works.

Proximity sensors are becoming common switching devices because they can detect the presence or absence of almost anything, without requiring physical contact. They have a reputation for accuracy, reliability, and longevity. Proximity sensors are often used to replace less accurate and more cumbersome mechanical switches. There are several types of proximity sensors, but the capacitive proximity switch has the greatest variety of applications. The proximity switch is often located along an assembly line or conveyor belt. See **Figure 11-B.** The capacitor emits and receives magnetic lines of flux, similar to the way a magnet emits magnetic lines of flux beyond the presence of the magnet itself. Unlike a magnet, these lines of flux are not designed to attract metal objects, but simply to detect the presence of an object. When an object is within the flux lines, the lines become distorted. A solid state switching device interprets the distortion and sends a signal indicating the presence of the object.

Figure 11-B. A proximity sensor detects the presence of a part and sends a signal that can be used to perform a function, such as counting or timing. (Balluff)

Processes

Processing functions are at the heart of programmable control. They generally include timing, counting, and recursive functions that can be easily programmed and quickly modified. This ability to easily program functions and modify the program without having to change hardware provides programmable control with a huge advantage over other forms of control. Assume you have a certain process along an assembly line that requires a heat lamp to come on for 30 seconds to dry wet paint every time a part passes a ***proximity sensor*** located alongside the conveyor belt. This is a typical ***timing function***. Such a task could be accomplished with a cycle timer, but it is easily accomplished via programming with a microcomputer or a PLC. Now, assume an indicator bell is supposed to ring as every twelfth part passes down the same conveyor belt. This ***counting function*** could be accomplished with a simple counter, but a microcomputer or a PLC could also perform this task. Finally, assume we want the whole process of paint drying and parts counting to start over again after the twelfth piece has been counted. This ability to make something happen over and over again is known in programming terms as a ***recursive function***, or recursion. All programming languages used for control and automation provide for a means of creating a recursive loop.

Many languages that use lines of numeric code allow a GOTO statement. The GOTO statement sends the program back to a particular line of code, where a sequence can then begin again. Using a microcomputer or PLC can eliminate a great deal of expensive hardware. Both can perform many timing, counting, and recursive functions, eliminating the need for independent timers and counters. Factor in the power, ease, and convenience of programming, and you will really get a feel for the benefits of programmable control over other forms of control. Processes requiring multiple timing and counting functions can all be controlled from the same location, and the processes can be easily modified, simply by changing the program. For example, one common timing function is known as an ***on-delay function***. An on-delay is typically created to provide a margin of safety from the time the start button on a machine is pushed until the machine actually begins running. As the name implies, something will be turned on after the controller receives an input and a specified period of time has elapsed. **Figure 11-13** displays the code for

Proximity sensor: A device that responds to physical closeness and transmits a resulting impulse.

Timing function: A computer subroutine that observes and records the elapsed time of a process.

Counting function: A computer subroutine that indicates by units so as to find the total number of units involved.

Recursive function: The ability to make something happen over and over again.

On-delay function: A common timing function typically created to provide a margin of safety from the time the start button on a machine is pushed until the machine actually begins running.

Figure 11-13. A program written in the Logo programming language to perform an on-delay function in controlling a motor.

Description	Syntax
• name of program	to demo.on-delay
• waits until touch sensor 1 is pressed and sends a true signal to interface box	waituntil [touch1]
• creates a 10 second delay	wait 100
• orients interface to motor port C	tto ``motord
• turns motor C on for 45 seconds	onfor 450
• ends program	end

performing an on-delay function, using the Logo programming language. Notice that altering one line of the program could easily change the delay. Using a new value in the appropriate line could also change the amount of time that the motor operates.

Cycle timer: A device that turns a load on and off on a continuous cycle.

Latching: A function used to start a machine at the touch of a button and have it remain running indefinitely.

Unlatching: A function used to turn a machine off.

Memory: The ability of a control circuit to remember the last command it received.

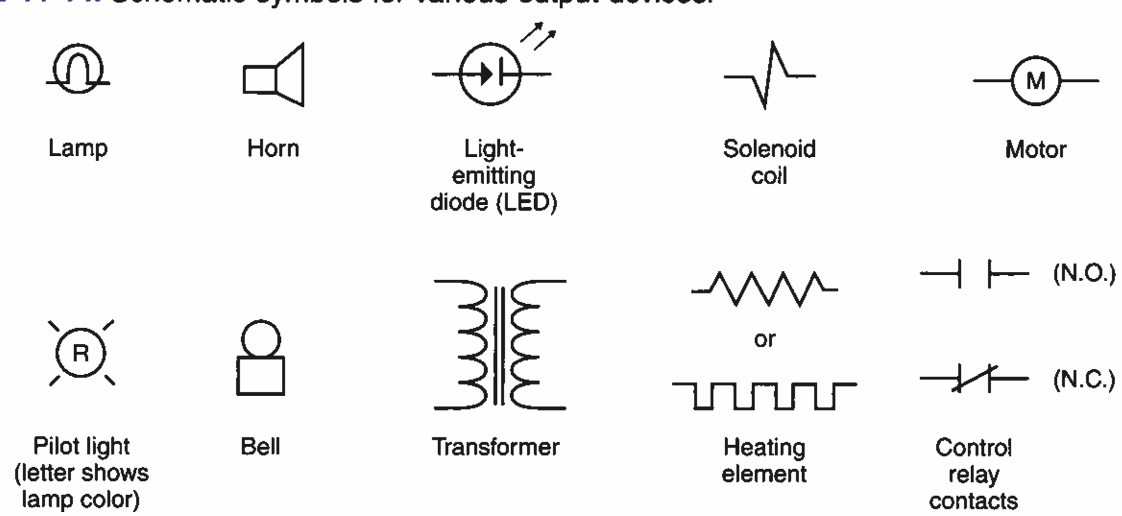
Typical processing functions include counting up, counting down, cycle timing, on-delay timing, off-delay timing, recursive loops, latching, and unlatching. A ***cycle timer*** turns a load on and off on a continuous cycle. A traffic light is a good example of a cycle timer. Other examples are a timer that turns a hot water heater on and off and a timer that turns lights on during certain hours. Latching and unlatching functions are best described by relating them to the latch, or locking device, on a door. A ***latching*** function would be used when you want a machine to start at the touch of a button and remain running indefinitely, similar to the way a door would remain latched if someone locked it. An ***unlatching*** function will be used to turn the machine off. The start button would be programmed to latch, thereby providing power and keeping it flowing to the machine, even when the button has been released. In terms of control logic, this is referred to as ***memory***, or the ability of a control circuit to remember the last command it received. The stop button would be responsible for unlatching the control circuit, thereby stopping the machine.

Outputs

Output device: A small load that makes things happen, such as a relay, an indicator light, a horn, a bell, a solenoid-controlled valve, a heating element, and a small motor.

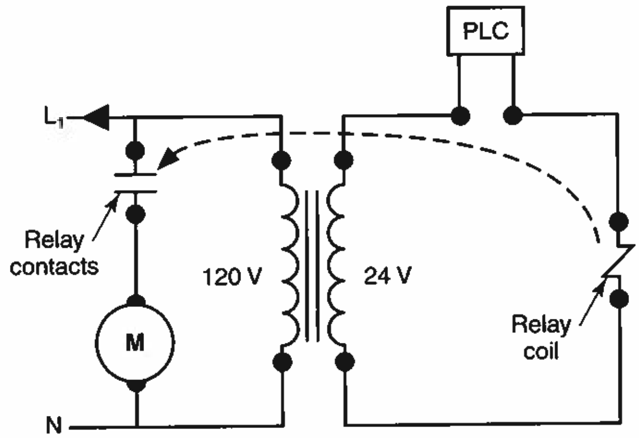
Electrical output from a microcomputer or PLC does not allow for the kind of high-amperage current flow that can directly power a heavy load, such as an electric motor. The small amounts of current that can flow through a microcomputer or PLC can, however, power smaller loads. Such loads are the ***output devices*** that make things happen. Typical output devices include relays, indicator lights, horns, bells, solenoid-controlled valves, heating elements, and small motors. The schematic (graphic) symbols for some common output devices are shown in **Figure 11-14.**

Figure 11-14. Schematic symbols for various output devices.



If a PLC or microcomputer must control a heavy load, the electricity from the control circuit is used to trigger an output device called a *relay*. Relays are switching devices that can be used to control high-amperage current flow to a heavy load, such as a motor. When the current from the processor energizes the coil on the relay, it closes the heavy relay contacts. This permits current flow to the motor. See **Figure 11-15.**

Figure 11-15. Using a relay in a low-voltage control circuit to control a motor or similar high-amperage load. The relay coil on the 24-volt side of the circuit is energized by a signal from a programmable logic controller (PLC). This closes the relay contacts on the 120-volt side of the circuit, sending current to the motor.



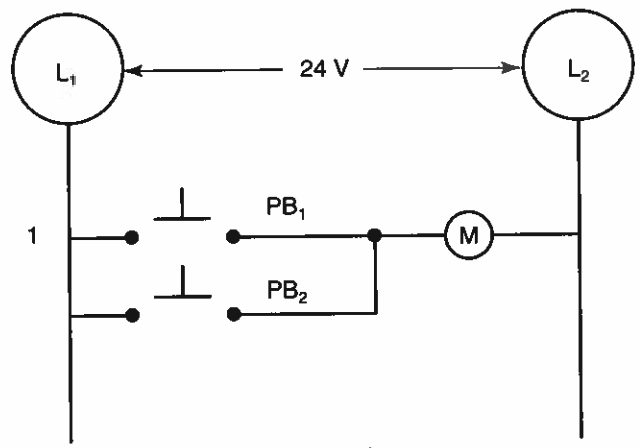
Control Logic

To fully understand, interpret, and design control circuitry, you must be familiar with the logic of such circuitry. The logic of control circuitry involves the way the input devices (switches and sensors) are arranged, in order to achieve the desired control function. For instance, in the example used at the beginning of this chapter, a heater was to function automatically, based on the set point of the temperature switch or thermostat. The circuit also called for a manual override switch. This gave the option of turning the heater on, regardless of whether the thermostat was calling for heat or not. The logic employed in this circuit is known as *OR logic* and is described in the next section.

OR Logic

One of the most common forms of control logic is ***OR logic***. Input must be received from either push button 1 OR push button 2 before the remainder of the program will execute. See **Figure 11-16.**

Figure 11-16. An OR logic circuit and truth table.



Truth Table

Input A	Input B	Output
0	0	0
0	1	1
1	0	1
1	1	1

Below the circuit diagram is a ***truth table***, a graphic method of representing the possible results from inputs. When reading truth tables, remember that *1* represents a true, or positive, signal, and *0* represents no signal. In the first row of the table in Figure 11-16, input A and input B both show as *0*. Since there are no inputs, there is no output—the output column also shows a *0*. In each of the other rows, input A or input B (or both) shows a *1*, so each results in an output.

OR logic: A form of control logic in which input must be received from either 1 OR more devices before output will occur.

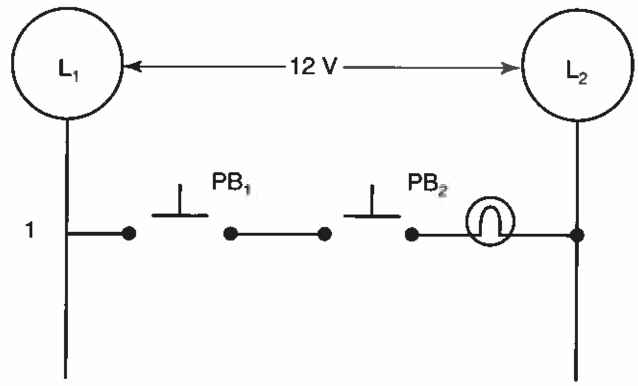
AND Logic

When input from two or more devices is required before an action can take place, ***AND logic*** is used. In the example provided, both push button 1 AND push button 2 must be pressed before any ouput will occur. See **Figure 11-17.**

Truth table: A graphic method of representing the possible results from inputs.

AND logic: A form of control logic in which input from two or more devices is required before an action can take place.

Figure 11-17. An AND logic circuit and truth table.



Truth Table

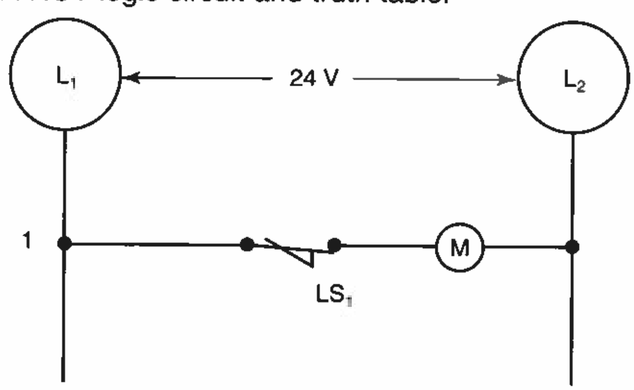
Input A	Input B	Output
0	0	0
0	1	0
1	0	0
1	1	1

NOT Logic

NOT logic: A form of control logic in which an output signal is provided *unless* there is an input signal.

NOT logic is employed when output is required *unless* there is a signal from an input device. This type of logic is often employed with interlocks and safety switches. So long as everything is in a normal state, the machine will function as intended. If a sensor signals that a guard is not in place or a door is open, however, NOT logic will shut down the machine. In the example shown in **Figure 11-18**, output will cease to occur if there is input to limit switch 1, which would cause the switch to open.

Figure 11-18. A NOT logic circuit and truth table.



Truth Table

Input	Output
0	1
1	0

NOR Logic

NOR logic is simply a combination of other forms of logic. It is a combination of NOT logic and OR logic. Review the truth table and line diagram in **Figure 11-19** to determine how NOR logic works in control circuits.

NOR logic: A combination of NOT logic and OR logic.

NAND Logic

NAND logic is a combination of two other forms of logic. It is a combination of NOT logic and AND logic. Review the truth table and line diagram in **Figure 11-20** to determine how NAND logic works in control circuits.

NAND logic: A combination of NOT logic and AND logic.

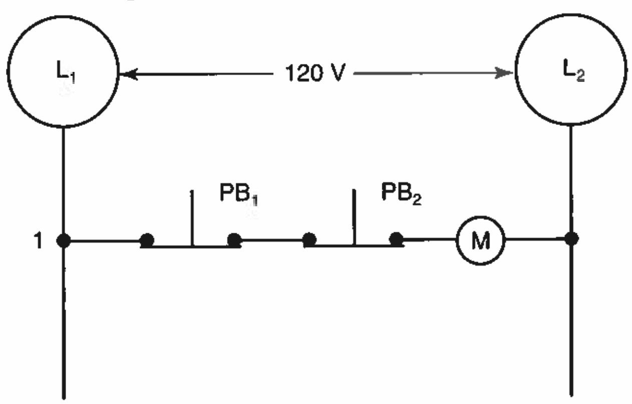
Creating Memory in a Control Circuit

Many control circuits require memory. The switch on your stereo or computer works this way. Push it once, and it turns on. Push it again, and it turns off. In such switches, the memory is created mechanically—the switch contacts are simply held in place by the design of the switch. Industrial control circuits often create memory with the use of a control relay or motor starter. These devices are designed to magnetically create memory. **Figure 11-21** shows a standard magnetic motor control circuit with start and stop buttons.

Pushing the start button sends power to the coil, causing the contacts to close. The contacts provide power to the load (in this case, a motor). The motor starter also includes a special set of contacts (known as ***sealing contacts***, or auxiliary contacts) that are part of the control circuit. When these contacts close, they maintain memory, bypassing the start button and feeding power to the coil of the motor starter. Pushing the stop button interrupts the flow of power to the sealing contacts, opening all contacts on the motor starter. Once the sealing contacts are open, they have no way to close themselves unless the start button is pressed again.

Sealing contact: A contact in a motor starter that is part of the control circuit. When these contacts close, they maintain memory, bypassing the start button and feeding power to the coil of the motor starter.

Figure 11-19. A NOR logic circuit and truth table.

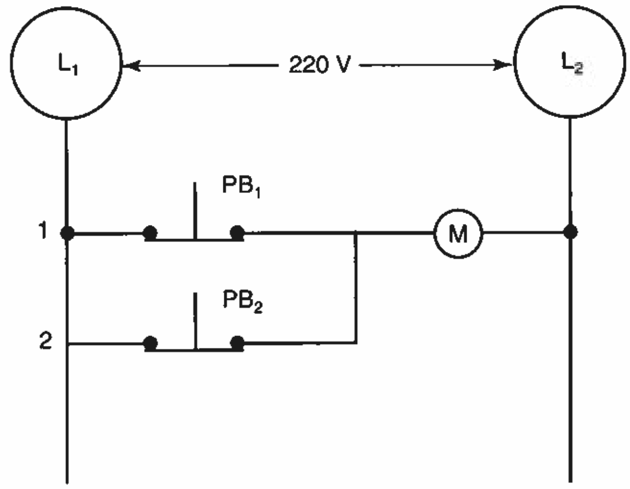


Truth Table

Input A	Input B	Output
0	0	1
0	1	0
1	0	0
1	1	0

GREEN TECH
Many people believe that using digital media instead of traditional media, such as books, is more environmentally friendly. However, electronic media waste not only contributes to landfills, it may also contain harmful chemicals, such as lead and mercury.

Figure 11-20. A NAND logic circuit and truth table.

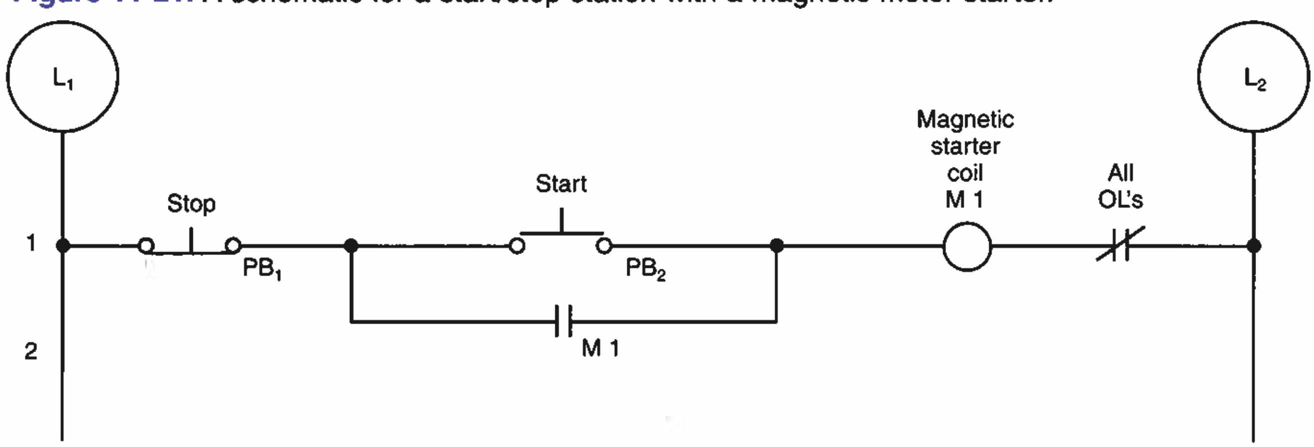


Truth Table

Input A	Input B	Output
0	0	1
0	1	1
1	0	1
1	1	0

Magnetic contacts, such as the one in this example, have several advantages over mechanical switches. First, if the power goes out and you are operating something with a mechanical switch, what happens when the power comes back on? The machine would start running again without warning! With a magnetic contactor, the control circuit would open when the power goes out, and the machine would not start again until the start button is pushed. Now, what if you are operating a large machine like a printing press? You might want the ability to stop the press from many locations, but to start it from only one. This is easily accomplished with the use of a magnetic motor starter, such as the circuit shown in Figure 11-21.

Figure 11-21. A schematic for a start/stop station with a magnetic motor starter.



Summary

Control technology and automation play a significant role in contemporary society. Control systems that function without regard for the system outputs are known as open loop systems. Those that use sensors to provide feedback are known as closed loop systems. There are four levels of control technology. They are manual, automatic, programmable, and intelligent control. Each level builds on the previous level, while providing for increased capability. All control systems include inputs, processes, and outputs. Inputs can be arranged within control circuitry in many ways to create various forms of control logic, including AND, OR, NOT, NOR, and NAND logic. Control circuits are often represented by line diagrams, which are sometimes referred to as ladder diagrams. These diagrams indicate all components in a control system in a visual way that allows for the creation and troubleshooting of the circuit.

Key Words

All the following words have been used in this chapter. Do you know their meanings?

analog signal
analog-to-digital converter (A/D converter)
AND logic
automatic control
binary-coded decimal (BCD)
closed loop system
counting function
cycle timer
digital signal
false signal
intelligent control
latching
line diagram
manual control
memory
NAND logic
NOR logic
NOT logic
on-delay function
open loop system
OR logic
output device
programmable control
programmable logic controller (PLC)
proximity sensor
recursive function
sealing contact
set point
timing function
true signal
truth table
unlatching

Test Your Knowledge

Write your answers on a separate sheet of paper. Do not write in this book.

1. List three rules for creating line diagrams.
2. Information sent back to a programmable logic controller (PLC) or computer from sensors is referred to as _____.
3. Describe why PLCs are so prevalent for control and automation applications in modern industry.
4. Explain the difference between the four levels of control technology.

5. Sophisticated software that emulates the human thought process is most commonly associated with _____.
6. Variable information, such as the percentage of light available in a room, would be considered _____ data.
7. Timing and counting are common _____ performed by a microcomputer or a PLC.
8. A process that cycles on again and off again every 30 seconds is an example of a(n) _____.
9. A program that will perform the same function over and over again is in a(n) _____.
10. Provide an example of an application for on-delay logic.
11. On-delay and off-delay are two common types of _____ functions.
12. Latching and unlatching functions can be used to create _____ in a control circuit.
13. Define inputs, processes, and outputs.
14. A horn may be sounded by pushing either one of two switches. This control circuit was designed to use _____ logic.

Matching questions: For Questions 15 through 21, match the phrases on the left with the correct term on the right.

15. _____ Visual representation of a control circuit.
16. _____ Level of control that makes use of sensors to replace manual inputs.
17. _____ Computer used exclusively for control purposes.
18. _____ Primary application for a PLC.
19. _____ Positive signal from a sensor.
20. _____ Numerical means of converting analog data to digital data.
21. _____ Pilot lights, relays, and motors.

A. PLC.
B. Automatic control.
C. Binary-coded decimal (BCD).
D. Counting function.
E. Line diagram.
F. True signal.
G. Programmable control.
H. Output devices.
I. Manual control.
J. AND logic.

STEM Activities

1. Determine the types of control circuitry necessary for an appliance, such as a washing machine or dishwasher, to work.
2. Look at a piece of industrial equipment, such as a saw, a mill, or a printing press. Draw a schematic indicating how you think the control circuitry operates.
3. Arrange for a tour of a factory or some type of production facility. Speak with the person who is responsible for keeping the machinery functioning properly about the control circuitry of the machines and the kinds of skills necessary to trouble-shoot these machines.