CHAPTER 17

Robotics

Objectives

- Identify technological developments that led to modern robotics.
- Explain how the stepper motor is used in robotics.
- Define *work envelope*.
- Explain how feedback control is used.
- Describe four types of modern robots.

Vocabulary

- **robot**
- **robotics**
- **controller**
- **computer program**
- **manipulator**
- **end effector**
- **power supply**
- **degree of freedom**
- **work envelope**
- **feedback control**

Did you know some robots work in hospitals? This one is helping deliver meals.

Activities

- Trial and Air
- Arming Yourself with Hydraulics

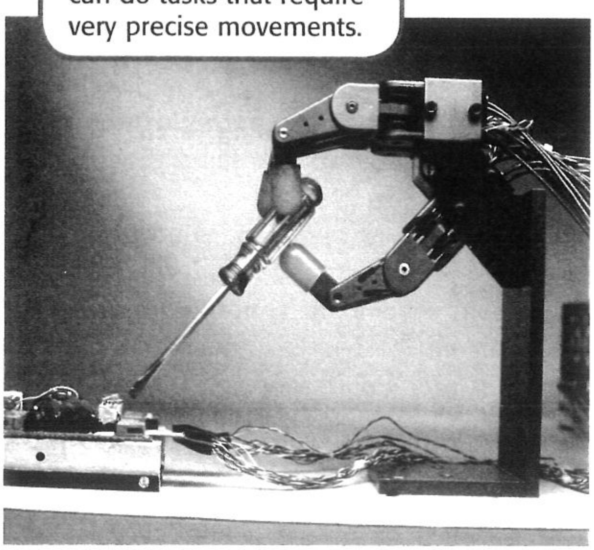
How Robotics Developed

A **robot** is a machine that does complicated tasks and is guided by automatic controls. **Robotics** is the design, construction, and operation of robots. We think of robots as marvels of modern technology. However, the idea of machines designed to imitate human actions existed over 3,000 years ago. The ancient Egyptians made puppets on strings.

During the 1700s, automata were popular in Europe. Automata were mechanical devices that imitated the actions of people or animals. One of the most famous automatons was a duck built by the French engineer Jacques de Vaucanson. This duck could walk, flap its wings, and even "eat." While the automata had no practical purpose, building them did encourage the development of technology. For example, de Vaucanson was the first European to make hoses from a "new" South American material—rubber.

Once computers were developed that could control robotic systems, robotics began to grow rapidly. The automata, computers, and other technological developments have led to today's modern robots.

Fig. 17-1. Today's robots can do tasks that require very precise movements.



Reading Link

What's the Big Idea? Based on your reading, identify what these three words have in common: puppet, automata, computer.

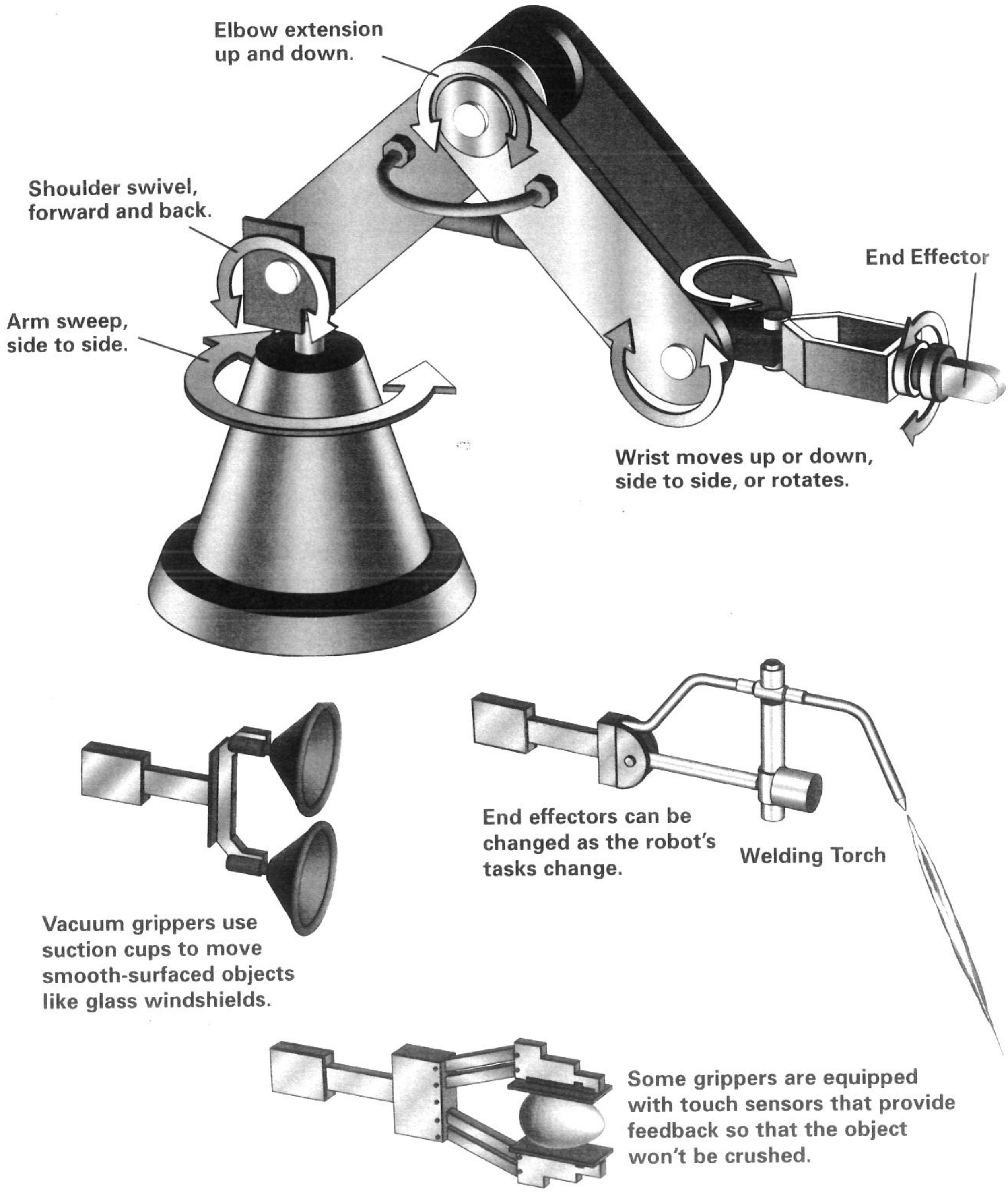
Robot Generations

The first generation of robots was designed for factory work. Known as steel collar workers, these robots did simple tasks that were dangerous or unpleasant for human workers. Early robots were used to handle hot metal, weld metal parts, spray paint, move parts, and load pallets. These early robots were large and not very flexible.

The second-generation robots used today can perform more complex tasks and simulate many human functions. They move, sense their surroundings, and respond to changes in the environment. Today's robots are flexible, and they can quickly be taught to do several different operations. With movements accurate to a fraction of a millimeter, robotic arms can assemble intricate electronic circuits. They can solder wires as thin as a human hair. See **Fig. 17-1**.

While many robots are mechanical arms attached to a base, some robots are independent. The robot shown on the opposite page is able to move through rooms and hallways and can even use elevators. It is controlled by a central computer and wireless radio. The robot can transport meals, medicine, lab samples, medical records, and supplies.

Fig 17-2. The manipulator uses cables, motors, gears, and pneumatic cylinders to move within a space. The movements are controlled by a computer program.



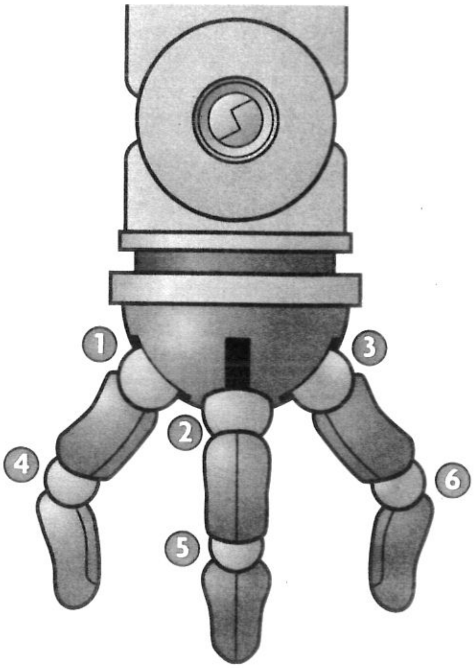


Fig. 17-3. This robotic hand has six degrees of freedom, and the wrist can turn 360 degrees.

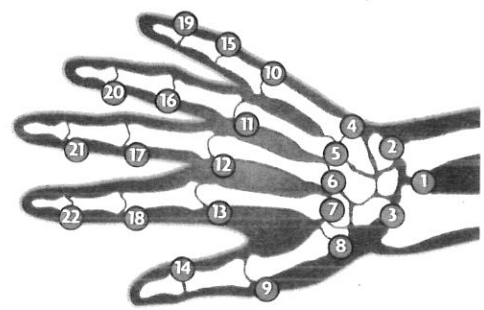
Robotic Systems

In many ways, robotic systems model human systems. In order for you to move, your brain has to send signals to your arms and legs. In order for a robot to move, a computer sends signals to it. Computers are the brains of modern robotic systems. A robotic system includes the following:

- The **controller** is a tiny computer that acts as the robot's brain and contains the computer program.
- The **computer program** is a set of coded instructions the robot must follow.
- The **manipulator** is the robot's mechanical system. It is often jointed so the robot can move, and it may resemble a human arm or torso. See **Fig. 17-2**.
- The **end effector** is the robot's hand. It may be in the form of a gripper, or it may hold an attachment, such as a welding torch or a paint sprayer nozzle. See **Fig. 17-2**.

Science Link

Joints and Motion. The joints of the fingers, wrist, and elbow allow freedom of movement in many, but not all, directions. Your hand and wrist have 22 joints, or degrees of freedom. Explore the ability of your joints to move in many directions. Attempt to move your fingertip, thumb tip, entire finger, entire thumb, hand, and forearm in (1) a pivoting (circular) motion, (2) a back-and-forth motion, (3) an up-and-down motion. Hold the body part above the joint to immobilize it. This will make it easier to identify the directions in which the joint allows movement.



- The **power supply** provides power to the robot. It may supply electricity, hydraulic power, or pneumatic power. These different sources all affect the type of work a robot can accomplish.

Degrees of Freedom

A robot's **degree of freedom** is its ability to move in a particular direction. Each degree of freedom requires a separate joint. Most robots have at least six degrees of freedom, and some have many more.

While a robot's freedom of movement is more limited than a person's, its range of movement is greater. Your wrist can bend only about 165 degrees, but a robot's wrist can spin 360 degrees. See **Fig. 17-3**. Just think how easy it

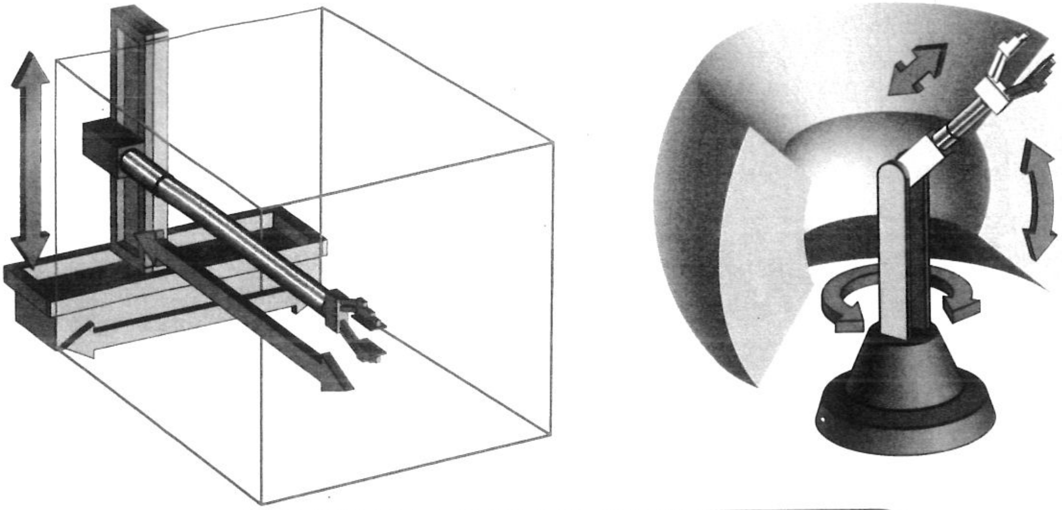


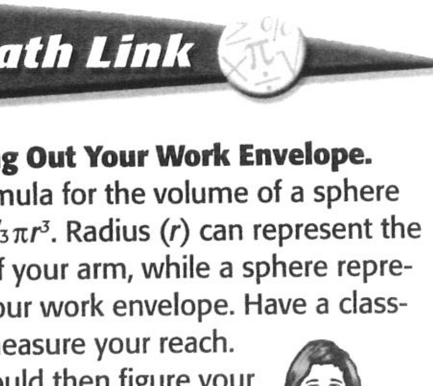
Fig. 17-4. The area a robot moves within is called its work envelope. The size of the robot and its degrees of freedom determine the size of the work envelope. What is the size of your work envelope?

would be to spin an object if our hands could turn completely around!

The space within which a robotic arm moves is called its **work envelope**. The design, or architecture, of the robotic arm will determine the size and shape of its work envelope. See **Fig. 17-4**.

Math Link

Working Out Your Work Envelope. The formula for the volume of a sphere is $V = \frac{4}{3}\pi r^3$. Radius (r) can represent the reach of your arm, while a sphere represents your work envelope. Have a classmate measure your reach. You should then figure your arm's work envelope.



Power for Robotic Movements

Moving robotic parts can be powered in various ways. The selection of a power source, or actuator, depends on what the part has to do.

An electric motor known as a stepper motor is commonly used as an actuator when robotic movement has to be fast and accurate. See **Fig. 17-5**.

One complete rotation of a stepper motor can be divided into hundreds of individual steps. Each step represents a fraction of a degree of movement. A stepper motor can rotate a small amount, or a step, each time an electrical signal is sent to it. Waist, shoulder, elbow, and wrist joints may each be powered by separate motors. The motor shaft transmits the mechanical energy through gears, shafts, and pulleys to the robotic joint. Computer programs control the precise movements of each joint by controlling the steps of the motor.

At times, robotic arms must lift heavy objects. Pneumatic and hydraulic actuators use compressed air or hydraulic fluids to transfer

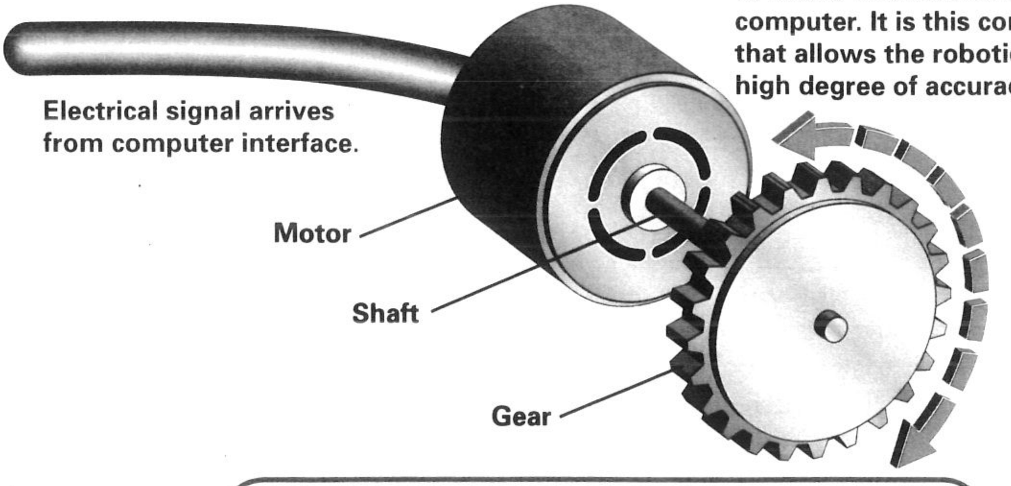


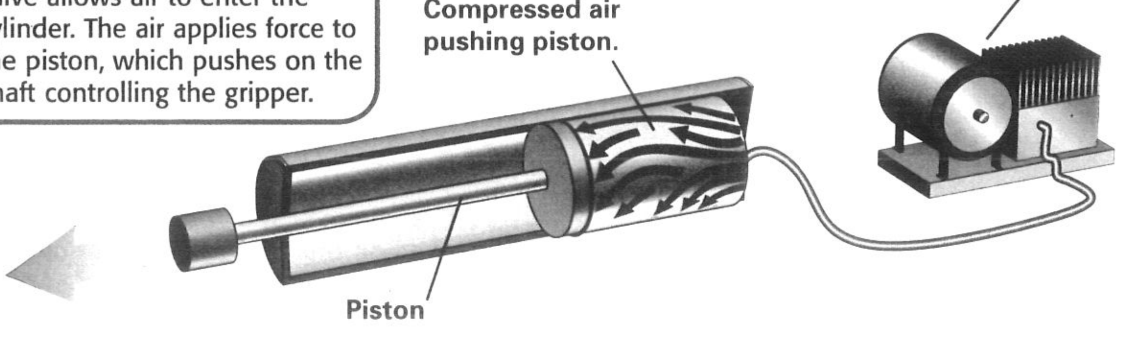
Fig. 17-5. Stepper motors provide the force to move the robotic arm. Gear trains and chain drives transfer mechanical energy from the motor to the moving part of the robotic arm. Gears are used to adjust the speed of the motors.

power to the joints and grippers. Pneumatic and hydraulic systems are made up of cylinders and pistons. The piston pushes on the fluid in the cylinder. A second piston on the other end of the cylinder moves as the fluid presses on it. The moving piston can make the robotic arms move forward and back. The pistons are controlled by electrical switches connected to computers. The switches open and close valves controlling air or hydraulic fluids. See **Fig. 17-6**. To learn more, see the "Fluid Power" interactive lab on the Student CD.

Controlling Robotic Systems

How does a robotic arm know what movement to make? How much pressure should the gripper apply? How can a robotic arm "remember" the patterns needed to paint an automobile? Just as your brain controls your every movement, computers control the movement of robotic systems. The computer uses a series of instructions known as a program. Robotic

Fig. 17-6. In this pneumatic system, a computer-controlled valve allows air to enter the cylinder. The air applies force to the piston, which pushes on the shaft controlling the gripper.



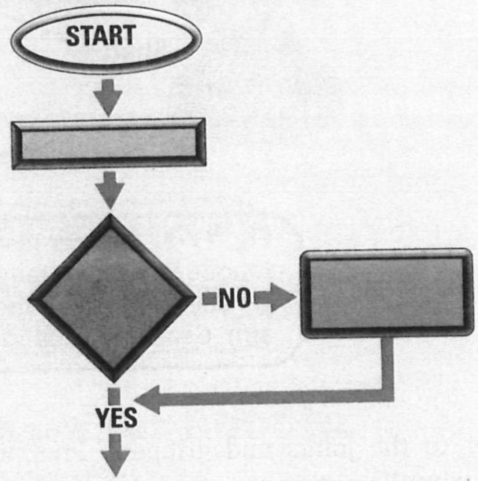
programs are very complex. They must list in logical order all the steps needed for the robot to perform a task.

Robotic software (program) designers prepare flowcharts that list the basic movements of the robot. These movements are then broken down into finer detail and written in a programming language. That language is converted into binary code, a series of 0's and 1's. The binary code contains instructions that tell the robotic arm how far to travel, how much pressure to apply, or how to move a tool to perform a task. You'll find more information about the binary system on the Student CD.

The instructions travel through cables of wire from the computer to the robotic interface. The interface links the computer to the robotic motors. Inside the interface are electronic switches that turn the motors on and off. The interface reads the binary code and produces signals that rotate stepper motors or open pneumatic valves, causing the pistons to travel. See **Fig. 17-7**.

Writing Link

Flowchart In, Garbage Out. Learn about flowcharts on the Student CD. Make a labeled flowchart that provides instructions for a robot to take out the garbage.



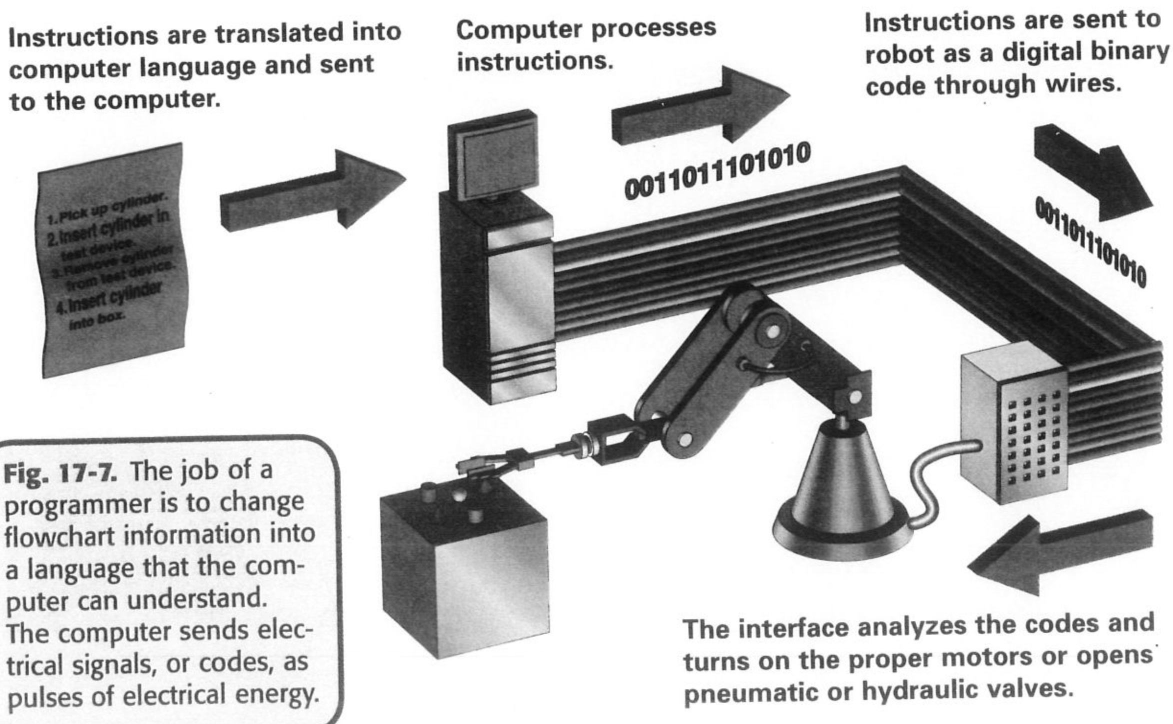


Fig. 17-7. The job of a programmer is to change flowchart information into a language that the computer can understand. The computer sends electrical signals, or codes, as pulses of electrical energy.

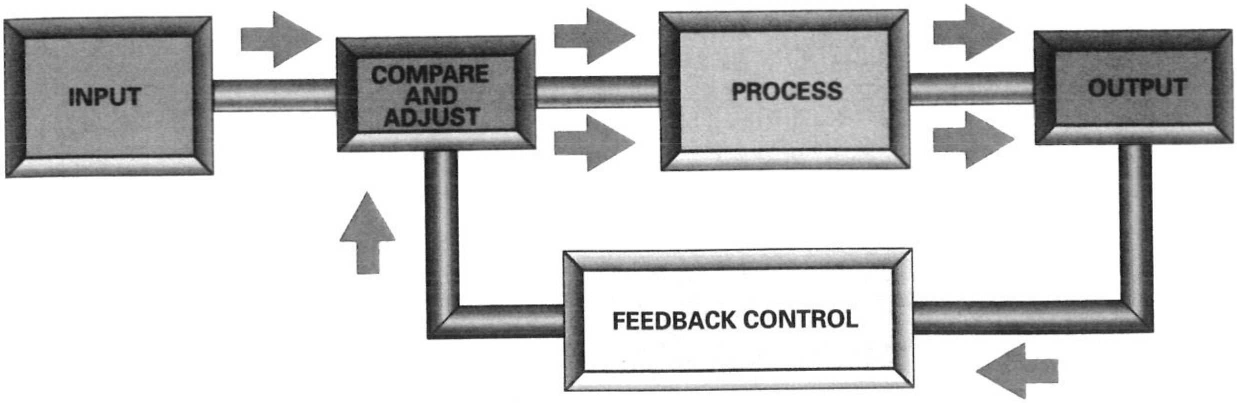


Fig. 17-8. The feedback control process. On robotic systems, sensors monitor what the system is actually doing. If the input to the system does not match the output to the system, the system is adjusted.

Lead-through programming is another way of controlling a robot. Instructions are created by guiding the robotic arm through a sequence of movements and programming the computer to remember the pattern of motion.

Robots can also be programmed using keyboards or teach pendants. The pendant and keyboard give the robot direct instructions to move up, down, left, and right. Each movement is remembered by the computer and repeated as often as required.

Feedback Control

How does a robot detect where an item is? Humans have sensory organs such as eyes, skin, and ears. These allow us to track changes in our environment. Robots also have sensors so they can keep track of what's going on around them.

Imagine that you are going to touch the handle of a saucepan on a stove. Your brain sends signals to the muscles and tendons in your hand, and you grasp the pot handle. Information is quickly sent to your brain through nerve bundles. The message is that your hand has grasped the handle and is ready for the next command.

What if the handle is too hot? Signals are returned to your brain and translated as pain. Your brain sends new signals to your hand and your grip is released. The process of sending signals, interpreting received signals, and adjusting through signals is called **feedback control**. Robots use feedback control constantly. It allows them to detect where they are and to adjust their actions. See **Fig. 17-8**.

Your fingers have over 17,000 sensors (nerve endings) that send data to your brain as you touch things. Robots use touch, or contact, sensors. These touch an object and send electrical signals to the computer. The data might include information on the shape of the object and how much pressure the grippers are placing on it. The computer can then adjust the actions of the robot if changes are needed.

A robot may be equipped with cameras so that it can view objects. The image picked up by the camera is sent to the computer for analysis. Using that data, the computer outputs directions to the robot.

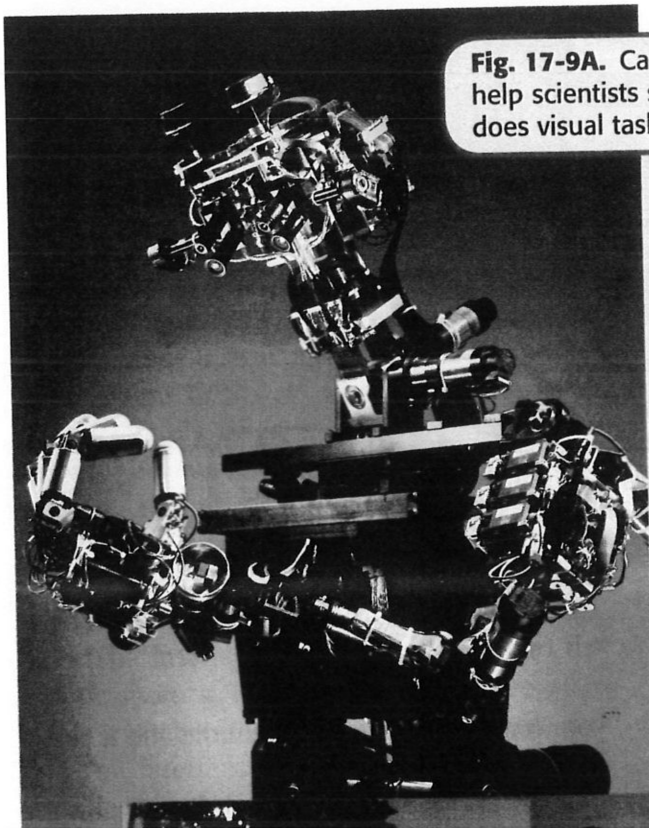


Fig. 17-9A. Cameras and sensors in this robot help scientists study how the human brain does visual tasks and controls movement.

Fig. 17-9B. This robot flower uses infrared sensors to detect movement. In response, it sways and changes color.

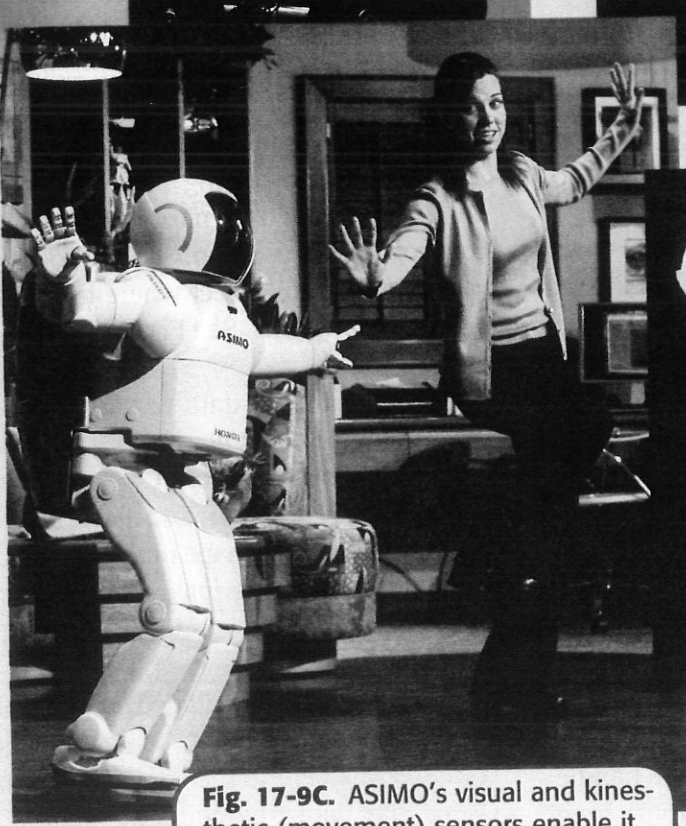


Fig. 17-9C. ASIMO's visual and kinesthetic (movement) sensors enable it to detect and respond to movement.

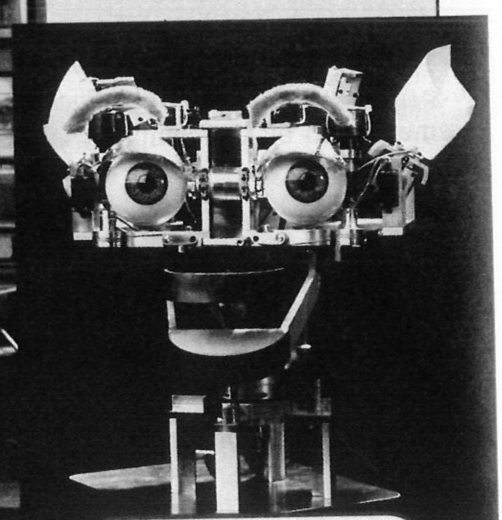


Fig. 17-9D. This robot's eyes and brain mimic human vision.

Impact of Technology

Robots in Industry

Automated manufacturing plants can operate with very few people. Robots can usually work faster, at lower cost, and more accurately than human workers. They don't even need a building's lights on to work!

Remember that robots are not paid a salary, are never late, never call in sick, never need health insurance, and never take vacations. Since using robots saves time and money, manufacturers can produce products more cheaply, allowing products to be sold for less and enabling the manufacturer to become more competitive in the world market.

Investigating the Impact

You've just read about advantages of having robots in manufacturing plants. However, impacts of technology can be both positive and negative.

1. What are some disadvantages of using industrial robots?
2. If robots are used instead of people, what problems might occur, both for the employer and for the employees?

Imagine freshly baked cookies moving down a conveyor line. Using its attached camera, the robotic arm looks for burnt and broken cookies. When one is sighted, the computer instructs the grippers to remove the bad cookie from the line.

Robotic arms that perform detailed work such as welding and painting use sensors to track the arm's movement. Disks displaying markings are placed at each joint in the robotic arm. As the joint moves, optical scanners (like cameras) read the markings. They send this information to the computer. The computer interprets the information, calculates the angle of the joint, and outputs needed commands to the arm.

There are many types of sensors. Robots may use microphones to sense sounds. They may use sonar to measure distances. The more complex the task, the more sensors a robot may need. See **Fig. 17-9**.

Modern Robots

Robots today come in a variety of shapes and sizes and are used for many purposes. Robots work in many places, from within the home to outer space. Some of them are mobile, while others remain stationary. Four useful types of modern robots include industrial, medical, assistive, and household robots.

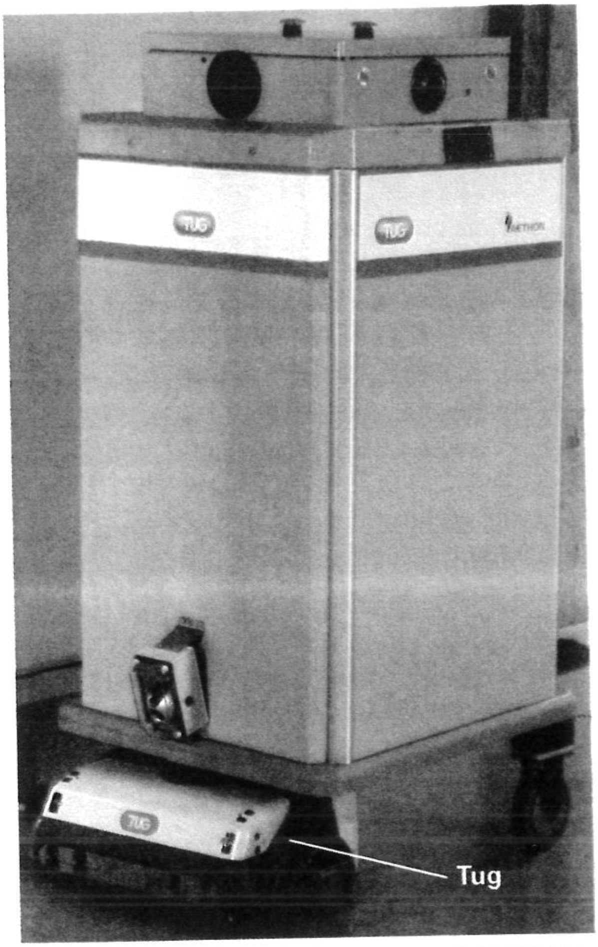


Fig. 17-10. Tug is a robot that can be trained to pull hospital carts. An onboard computer contains a map of the building. Users choose a destination and send Tug on its way.

Industrial Robots

Most industrial robots are robotic arms. They can do many factory jobs, such as welding, spray painting, and assembly. Industrial robots are often used to do jobs that are boring or unsafe for humans. The majority of robots today are industrial robots.

Medical Robots

Robots have become very valuable in the medical field. They can assist in surgeries, transport hospital materials, dispense medicine, and much more.

Surgeries are often delicate procedures. In some joint replacement operations, a hole must be drilled into the bone to accept the artificial joint. The accuracy of this hole is critical. Some surgeons now use robotic systems to position the drill and make the actual hole. The accuracy and steadiness of the robotic arm are hard to beat. Robotic hands also can work in areas that are too small for human hands.

Robots are also being used to fill hospital prescriptions. Errors in filling prescriptions are a leading cause of preventable deaths in hospitals. Robots are more accurate and have helped reduce prescription mix-ups.

The Tug® robot is used to transport goods throughout the hospital. In areas where health care workers are in short supply, Tug can carry medical records, food, and medications to where they are needed. See **Fig. 17-10**.

Robots can even be used to fill a void left by absent doctors. While doctors are often needed in many places at once, a robot can be remotely controlled by the doctor to visit patients. The top of the robot has a display screen that shows the doctor's face, so that patients can still interact with their own physician rather than a stranger.

Assistive Robots

People with disabilities may have a difficult time with everyday tasks. Assistive robots can help with tasks such as eating, cleaning, and grasping or reaching for objects.

For instance, a robotic arm attached to a wheelchair could pour a glass of milk for someone who is paralyzed. See **Fig. 17-11**. A robot with an extendable arm could reach objects on high shelves. Robotic arms can also easily hold a tray of food and even feed people who have difficulty feeding themselves.

Household Robots

Have you ever read a story or seen a show with a robotic butler or maid? In reality, robots already exist in some households, doing every-

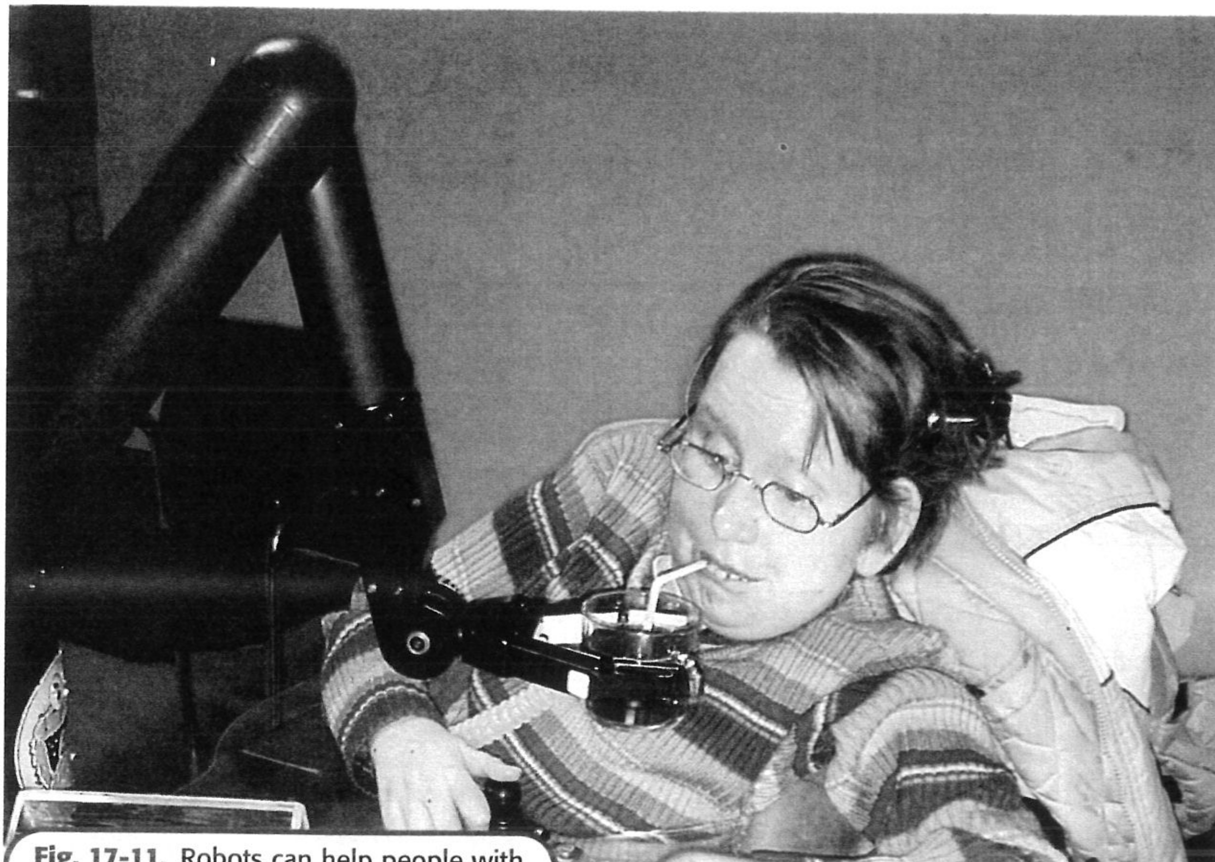


Fig. 17-11. Robots can help people with their daily activities. **What impacts might assistive robots have on society and the economy?**

day tasks. The Roomba vacuum cleaner was the first affordable house-cleaning robot. Roomba vacuums your floors when you have other commitments, such as watching football on television! The vacuuming robot can sweep under furniture, and it uses sensors to detect trouble spots that might need more thorough cleaning.

Do you find mowing the lawn to be tedious? Robomowers can mow your yard while you relax nearby. All you need to do is push a button on a remote control to operate it. See **Fig. 17-12.**

Fig. 17-12. Robomowers can cut grass in perfectly straight lines.

Exploring Careers

Engineering Technician

TECHNICAL

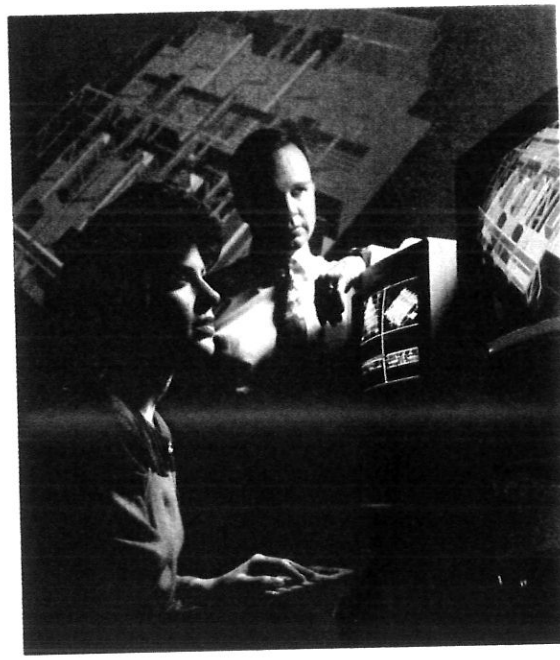
Engineers need help to design and build robots. Engineering technicians are key members of the team. They help the engineers build prototypes, collect and record data, and design the robot—often using computer-aided design.

Engineering technicians work in many kinds of jobs, not just robotics. Most specialize in one area, such as civil or chemical engineering. More than 40% of engineering technicians work in the electrical and electronics area.

Qualifications

A technician must have a good math and science background as well as good problem-solving skills. An associate's or bachelor's degree is required. The technical courses required will depend on the engineering area. For example, students who want to become electrical engineering technicians may need to take classes in microprocessors, electric circuits, and digital electronics. A mechanical engineering technician would most likely take courses in thermodynamics, mechanical design, and fluid mechanics.

Because many engineering technicians are helping with design, creativity is a good trait to have. Good communication skills and the ability to work well with other people on a team are also very important.



Outlook for the Future

The job outlook for engineering technicians is good. As with all jobs, both local and national conditions affect the outlook.

Lifelong Learning

If you choose this career, you should be willing to learn more as you progress through your work life. Employers want people who are willing to learn more about their chosen field and want to improve their skills.

Researching Careers

Find out about jobs for engineering technicians in the field of robotics. What are the educational requirements? Where in your area can you meet those requirements? Write a brief summary of what you find.

CHAPTER 17 Review

More activities on Student CD

Key Points

- A robot is a machine that does complicated tasks and is guided by automatic controls. Robotics is the design, construction, and operation of robots.
- Robots use joints to move. These joints give robots degrees of freedom.
- The stepper motor is a common power source for robotic movement.
- Computers are used to operate a robotic system.
- Robots depend on feedback control.
- Modern robots are used for a variety of purposes.

Read & Respond

1. How are robots similar to humans?
2. What important technological developments had to take place before robotics control system technology could become a reality?
3. How does a robotic arm achieve degrees of freedom?
4. Explain how the stepper motor is used in robotics.
5. Define the work envelope of a robotic arm.
6. List three end effectors commonly used on robots.
7. Explain how feedback control is used to adjust a robotic arm's movements.
8. Where are robots used the most?
9. What is a robot's manipulator?
10. Name four types of modern robots.

Think & Apply

1. **Plan.** You are the owner of a company that manufactures small appliances. You have decided to add robots to the assembly process. Describe the plans you have for the workers who will be displaced by your actions.
2. **Organize.** Prepare a list of tasks usually performed by people in their homes that could be done by robots.
3. **Design.** Prepare sketches of a robotic arm that could turn pages in a book for a person who is paralyzed. Label the parts.
4. **Summarize.** Describe the factors that affect the adoption of robotics technology by manufacturers.
5. **Evaluate.** While in a hospital, you are visited by a robot that has a display screen showing your doctor's head. Describe the pros and cons of this robot.

TechByte

Learning to Walk, Robot Style. Scientists have created a robot that can learn to walk, just like people do. This robot uses gravity, along with springs and motors that imitate muscles, to move without using as much energy. While it starts walking by falling and catching itself just like a toddler might, the robot learns to walk in 20 minutes!