

Robotics

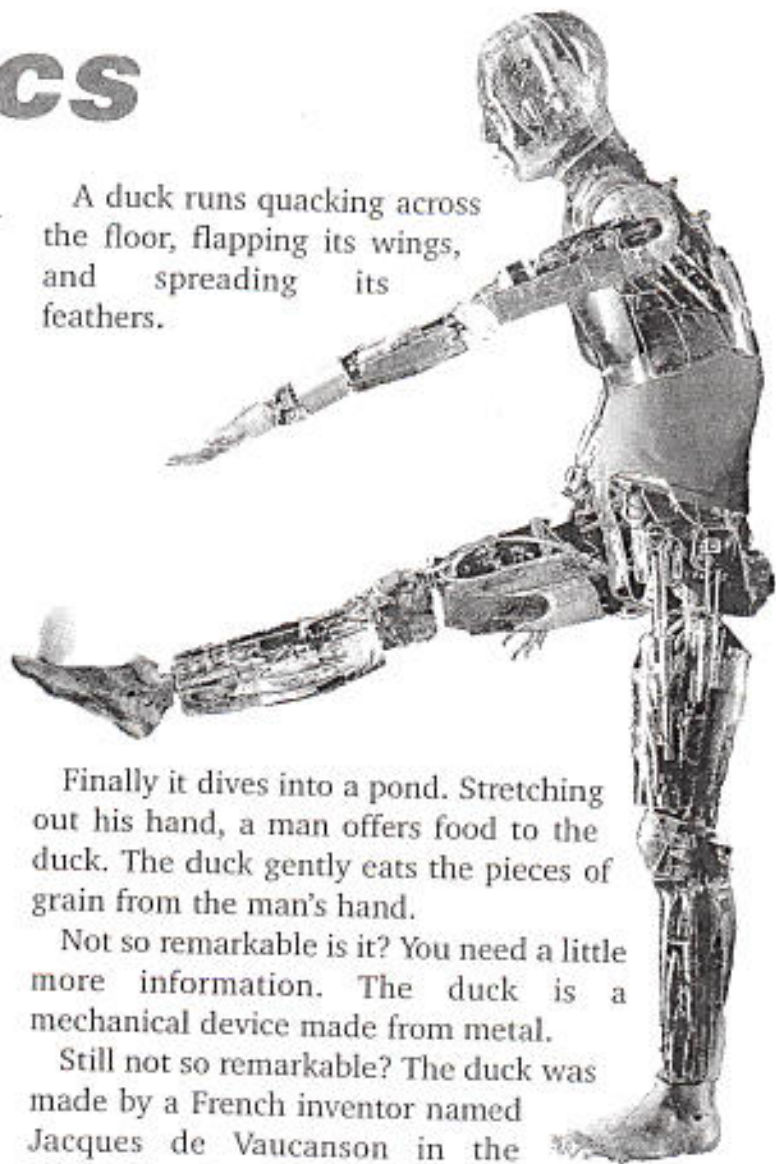
OBJECTIVES

- ▶ identify technological developments that led to modern robotics.
- ▶ explain how the stepper motor is used in robotics.
- ▶ define the work envelope.
- ▶ explain how feedback control is used.

KEY TERMS

automation
degree of freedom
feedback control
robot
robotics
work envelope

A duck runs quacking across the floor, flapping its wings, and spreading its feathers.



Finally it dives into a pond. Stretching out his hand, a man offers food to the duck. The duck gently eats the pieces of grain from the man's hand.

Not so remarkable is it? You need a little more information. The duck is a mechanical device made from metal.

Still not so remarkable? The duck was made by a French inventor named Jacques de Vaucanson in the 1700s. That's pretty remarkable!

We think of robots as marvels of modern technology. However, the idea of machines designed to imitate human actions existed over 3,000 years. The ancient Egyptians made puppets on strings.

HOW ROBOTICS DEVELOPED

The duck you just read about was a crude robot. A **robot** (ROW-bot) is a machine made to act like a living thing. **Robotics** is the study of robots. Robotics is a control system technology. Through input data and a variety of processes, people have learned to control the output of machines. Today, robots are designed to do many of the tasks humans used to do.

Ancient attempts at robotics were not control system technologies. Crude robots could not react to changing conditions as modern robots can. Many technological events had to take place before true robotics could develop. Designers and engineers had to learn how to transfer forces. They did this through gears and levers. The development of punch cards, computers, and automation was also important.

Modern Robots

Robots are used today in a variety of ways. For example, during some joint replacement operations in humans, 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.

Mobile robots can crawl into the most unusual places. The Mermaid is an underwater robot that searches the sea bottom for unexploded mines. It can hold onto the sea floor in the roughest current. When the robot locates the mine, it self-destructs by blowing itself up. This detonates the mine. Fig. 17-1.

Walking robots are capable of moving over rough ground and even up stairs. Police departments in large cities use walking robots to retrieve explosives from buildings.

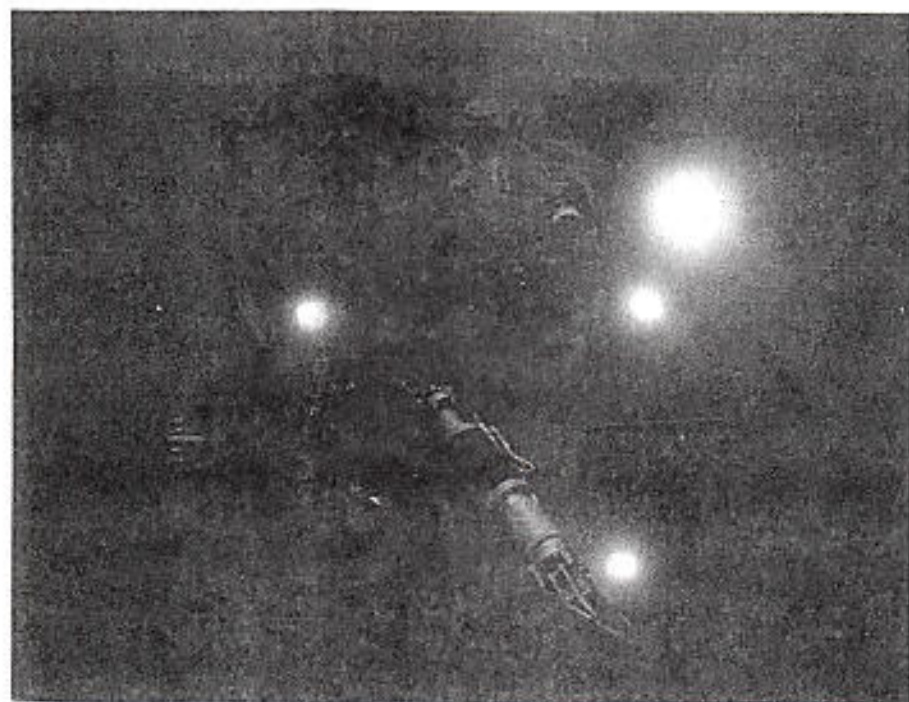


Fig. 17-1 The Mermaid, an underwater research robot. Notice the robotic arm in the foreground. It has a gripper that allows it to pick up items with extreme precision.

FASCINATING FACTS

When we look at a scene, we may disregard the 98% of the scene that is unimportant to us. When a robot looks at a scene, it cannot disregard anything. The robot sees everything. This means that it must process a dizzying amount of information. You can see that it is very difficult to make robots that have artificial intelligence.

Deep beneath the dark Atlantic Ocean robotic divers searched for the sunken ocean liner *Titanic*. The cameras and sonar on board the robotic diver sent signals to the computer on the mother ship. Suddenly, observers could see the hull of the great ship resting on the floor of the ocean.

Early Mechanisms

During the eighteenth and nineteenth centuries, mechanical robotics were built for entertainment purposes. These robots used springs, gears, levers, and pulleys to perform many tasks. These robots were called *automatons*. Some of them could play musical instruments, write letters with pen and ink, and even perform magic tricks.

In the early 1800s, Joseph-Marie Jacquard, a French weaver, invented a punch card system. He used it in his factory to produce fabric patterns. Holes were punched in stiff paper cards. These holes corresponded to patterns woven in fabric. Some rods were pushed through

the openings in the cards. Other rods were held back. This arrangement of rods represented the color and pattern of threads that the machine had to weave. The punch card process laid the foundation for modern computers.

Punch Cards and Computers

Herman Hollerith invented the punch card tabulating machine. The machine was used to tally data (information) during the 1890 United States census. Data was punched into the card. The machine inserted rods through the holes in the card. The rods then made contact in small cups of mercury, completing an electrical circuit. The electrical connection made the hands on a dial move one space. In this way data was recorded and added.

Hollerith had created an electrical scanner and sensor. This technology was essential to later developments in computer control technology. Hollerith's company later joined other companies to form IBM.

The first computers were built during the 1940s. They were huge calculating machines that took up an entire room. In 1948, a team of scientists invented the transistor. This reduced the size of the computer. It also multiplied the speed at which the computer could make calculations. Fig. 17-2.

Automation

Automation (auto-MAY-shun) is a technique that is used to make a process automatic. The word was first used in the 1940s. It described work that had been

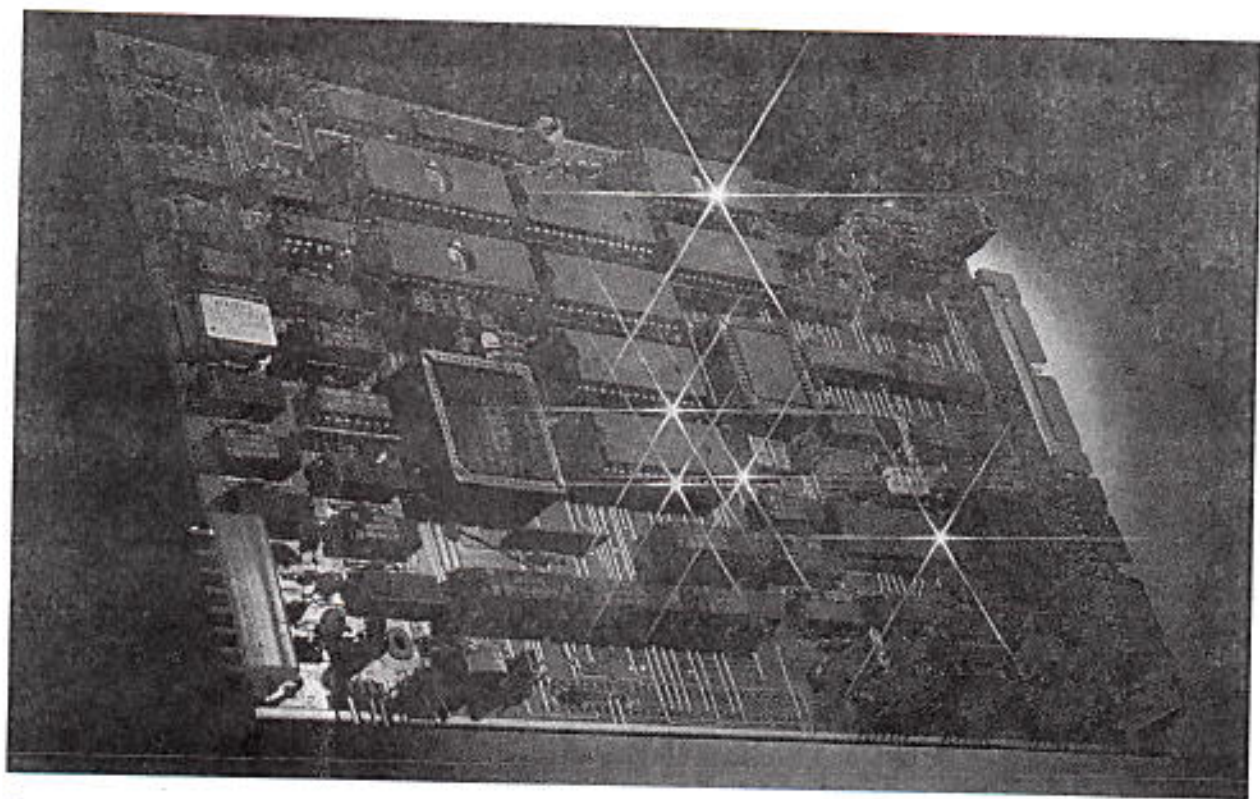


Fig. 17-2 The motherboard of a personal computer. It is a giant leap from the punch card tabulator to transistors, microchips, and personal computers. New technologies build upon old technologies. The personal computer created the foundation for modern robotic control.

done by people that was now being done by machines.

Automated factories used machine tools that were computer controlled. The most accurate machines at the time were numerical control machines. The system used numbers to describe the shape of a part and the tool's movement through the material. A punched paper roll (punched tape) had these movements recorded on it. This roll was fed through the computer. The machine tool would then automatically cut, grind, or drill the part to shape.

MODERN ROBOTIC SYSTEMS

Machine tools are not robots. Robots are more accurate. They are also more flexible and can make decisions. The word *robot* was first used in 1922 by Karel Capek, a Czechoslovakian writer. He wrote a play about mechanical humans, or robots. They worked in factories, where they replaced human workers. The Czech word *robota* means "slave labor." In Capek's play, the robots finally rebel against their masters—and take over the world!

Robots represent great power in today's workforce. By the 1970s, Japan had over 7,000 robots in automobile factories. These robots moved materials and parts. They welded, assembled, and painted automobiles on the assembly line.

Robotic systems are designed to have humanlike movements. In many ways, robotic systems model human systems. Just as your brain sends commands to your arms and legs, a computer sends instructions to a robot. Computers are the brains of modern robotic systems. They control the movement of mechanical robotic arms. Fig. 17-3.

Robotic Arms

There are sixteen joints in the human arm, wrist, and fingers. These joints provide us with forty degrees of freedom. A **degree of freedom** is the ability of the robot to move in a direction. Movement in a combination of joints allows human, as

Linking to SCIENCE

Joints and Motion. The joints of the fingers, wrist, and elbow allow freedom of movement in many, but not all, directions. 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.

FASCINATING FACTS

What if we could build machines molecule by molecule? The science of designing very tiny things is known as *nanotechnology*. Scientists are trying to design nanomachines. These would be small enough to work with individual molecules. They would be able to manufacture tiny products.

well as robotic, arms to move in any direction. The flexibility of these joints allows robots to handle a variety of materials in a variety of shapes. This flexibility gives robotic arms, or manipulators, the ability to move in any direction and grasp a variety of items.

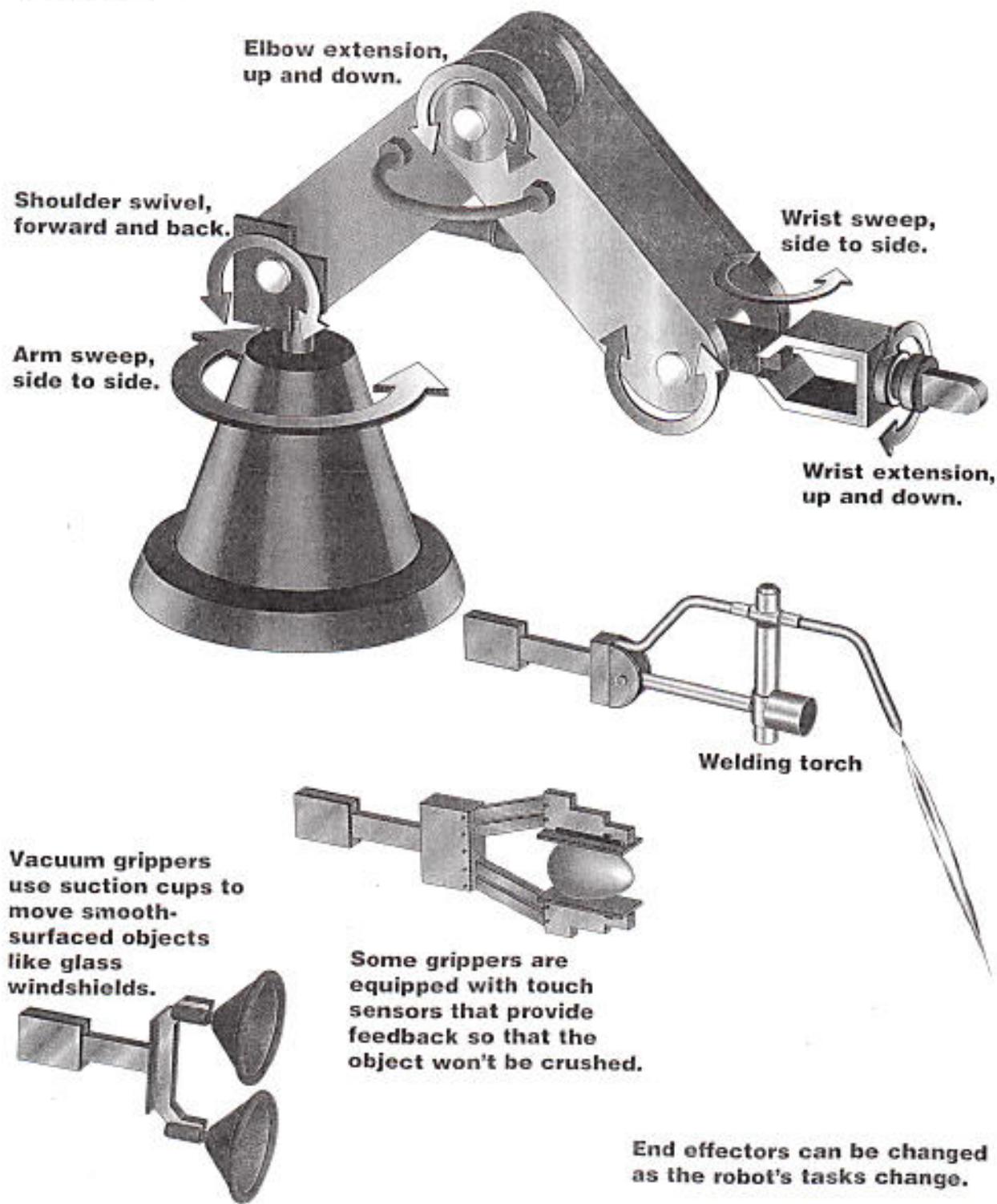
Robotic Hands

Human hands are very flexible. They can grip almost any object in a variety of positions. Robotic hands have a much more difficult time. Often a variety of robotic hands must be used as an assigned task changes. Robotic hands, known as *end effectors*, can quickly be attached to a robotic wrist as a task may change.

The Work Envelope

The place where two moving parts of a robot are connected is called a joint, or axis. An arm robot (manipulator) moves at its waist (or base), shoulder, elbow, and wrist joints. Each degree of freedom in a robotic arm is provided by combining the movements of these joints.

Fig. 17-3 Robotic arm and effectors. Robotic arms use cables, motors, gears, and pneumatic cylinders to move within a space. The arms receive directions from a computer much like our arms and hands receive instructions from our brain. Robotic arms move through space by rotating a combination of joints. A robot's degree of freedom is based on the number of joints it has and the degree of movement the joints allow.



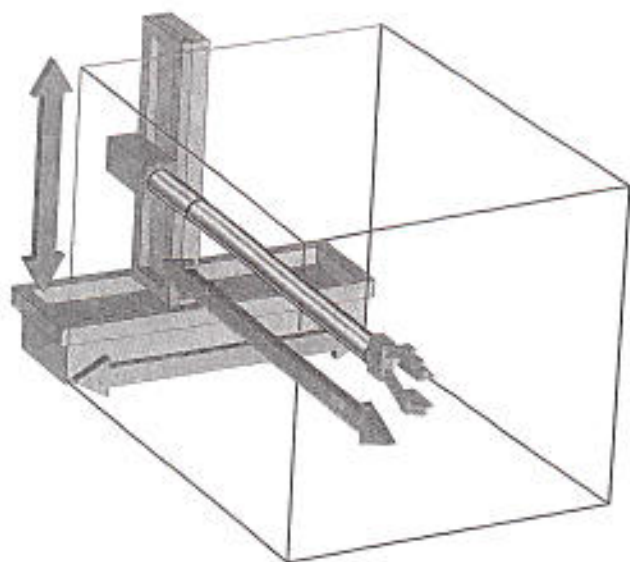
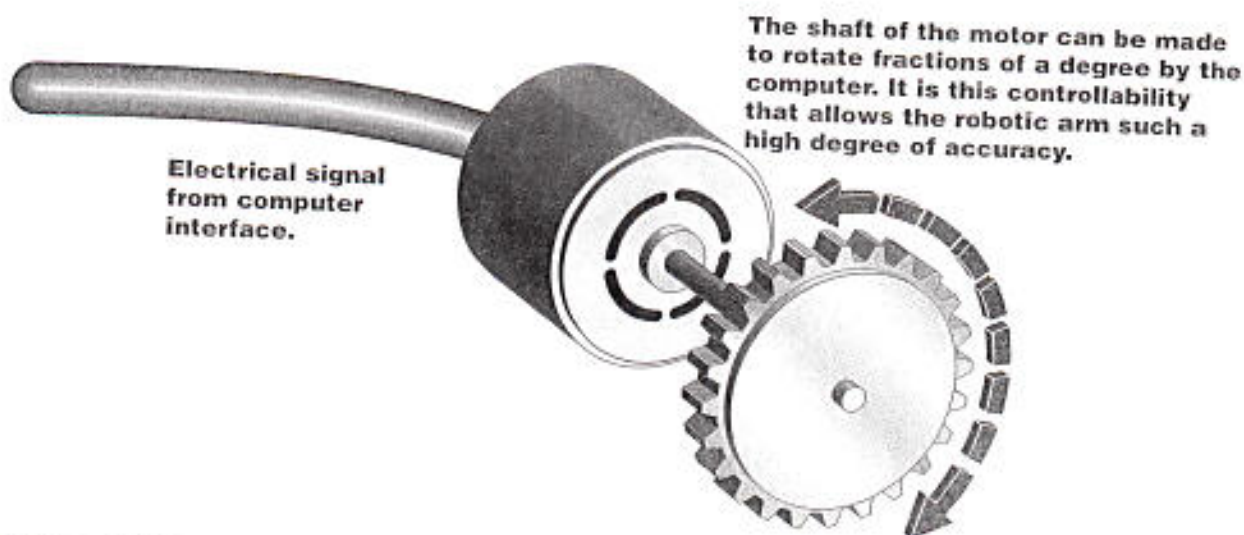


Fig. 17-4 The area a robot moves within is called its work envelope. The size of the robot and the degrees of freedom determine the size of its work envelope. What is the size of your work envelope?

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

POWER FOR ROBOTIC MOVEMENTS

Each moving robotic part can be powered in a variety of ways. The selection of a power source depends upon



The shaft of the motor can be made to rotate fractions of a degree by the computer. It is this controllability that allows the robotic arm such a high degree of accuracy.

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.

what the robotic arm has to do. An electric motor known as a *stepper motor* is commonly used as an actuator, or power source, for robotic movement. 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. Robot programmers control the precise movements of each joint by controlling the steps of the motor.

Electric stepper motors power robotic arms with speed and accuracy. At times, robotic arms lift heavy objects. Pneumatic and hydraulic power supply the extra force. Pneumatic and hydraulic actuators use compressed air (pneumatic force) or hydraulic fluids (hydraulic force) to transfer power to the joints and grippers. Fig. 17-6.

Linking to MATHEMATICS

The Work Envelope. What is the volume of your work envelope? Since you reach forward, backward, to the left and to the right, you reach a full three-dimensional circle, which is a sphere.

The formula for the volume of a sphere is $V = 4/3 \pi r^3$. Radius (r) is the reach of your arm forward or up or any direction. You are the center of your sphere of reach. For example, if your little sister's reach is 10 inches, her work envelope is:

$$V = 4/3 \pi r^3$$

$$V = 4/3 \times 3.14 \times 10^3$$

$$V = 4186.66 \text{ cubic inches}$$

Have a classmate measure your reach. You should then figure your work envelope.

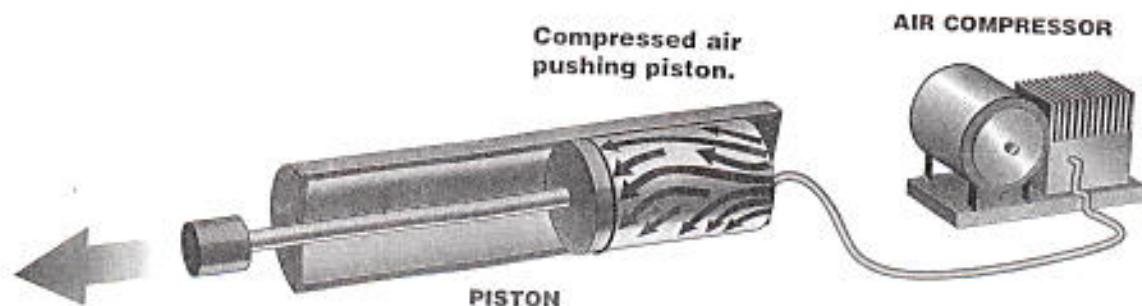


Fig. 17-6 In this pneumatic system, a computer-controlled valve allows air to enter the cylinder. The air applies force to the piston, which pushes on the shaft controlling the gripper.

Explore

Design and Build a Feedback Control Game

State the Problem

Your eyes send feedback to your brain about the movements of your hand. This feedback allows your brain to make constant corrections to your hand movements. This helps you to form letters, lines, and shapes. What would happen if your brain received the wrong feedback signals? In this activity you will design and build a device that will fool your brain.

Develop Alternative Solutions

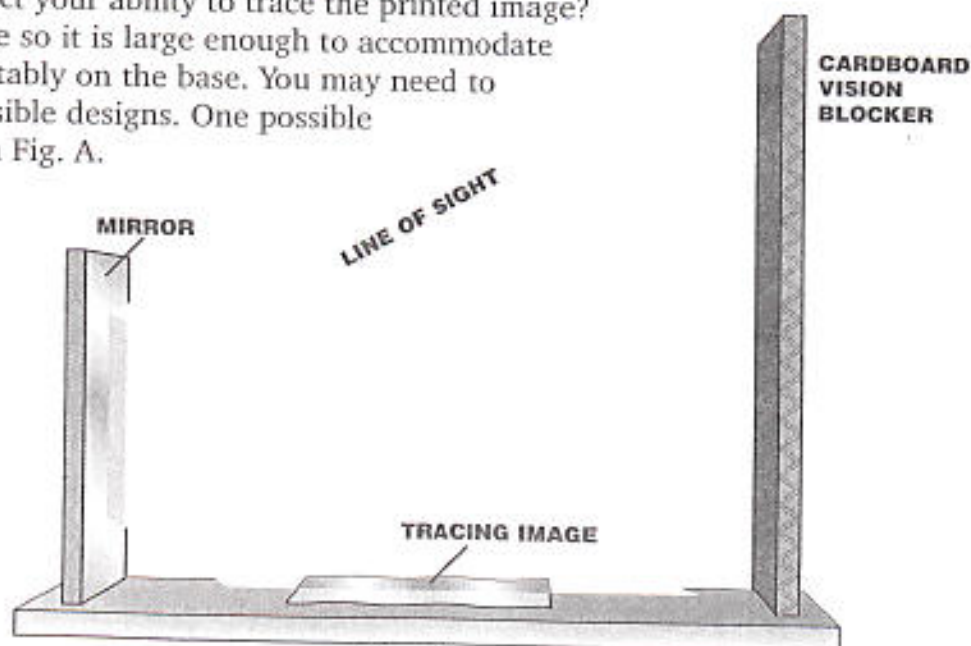
You will need to construct a device that will fool your brain and give it incorrect feedback. The device will contain a vision blocker that will keep you from directly seeing the image your hand will trace.

The only visual feedback your brain will receive regarding your hand movements will come from what you see in the mirror. As you know, mirror images are backwards or the reverse of the real image. How do you think this will affect your ability to trace the printed image?

Design the game so it is large enough to accommodate your hand comfortably on the base. You may need to create several possible designs. One possible design is shown in Fig. A.

Collect Materials and Equipment

base material (wood, plastic, cardboard)
mirror, glass or acrylic
cardboard (for vision blocker)
paper with printed images
material processing tools and machines



Select the Best Solution

Select the design that you think is most effective.

Implement the Solution

1. Build the game, using your design sketch as a guide. Be sure the vision blocker is large enough to block your line of sight. Be sure the mirror is placed to reflect the reversed image to your eyes.
2. Place the game on your desk. Sit behind it so the vision blocker prevents you from directly seeing the image printed on the paper.
3. Position yourself so that you can see the printed image only through the mirror.
4. With a pencil, trace the printed image using only the mirror as your feedback mechanism.

Evaluate the Solution

1. After playing the game for a while you will probably be able to trace the image more accurately. How can this be explained?
2. Are some images more difficult to trace than others? Why?

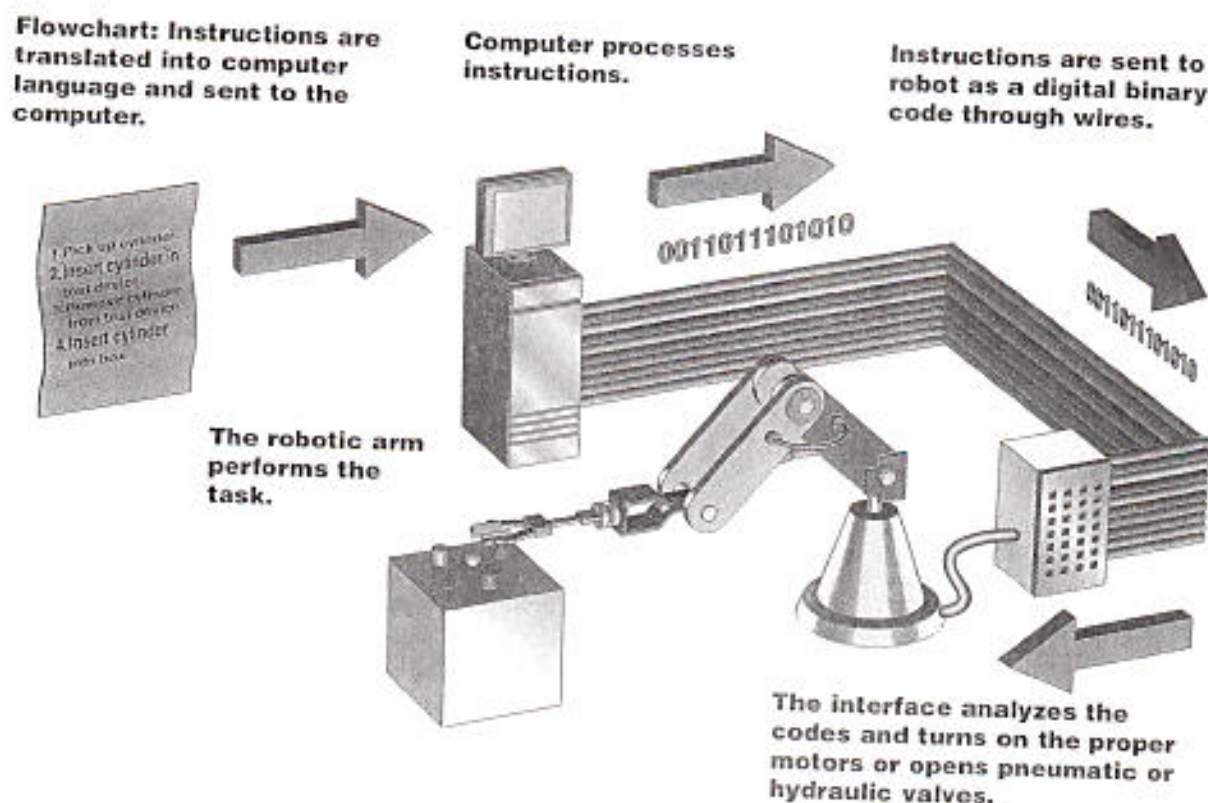
Pneumatic and hydraulic systems are made up of cylinders and pistons, much like a doctor's syringe. The piston pushes on the fluid in the cylinder. A second piston on the other end of the cylinder moves as the fluid presses on it. The moving piston can make the robotic arms move forward and back. The pistons are controlled by electrical switches connected to computers. The switches open and close valves controlling air and hydraulic fluids.

CONTROLLING ROBOTIC SYSTEMS

Binary Code

Cables of wire travel from the computer to the robotic interface. The *interface* links the robotic motors to the computer. Fig. 17-7. Inside the interface are electronic switches that turn the motors on and off. Electrical signals travel through the cable as coded information. The code consists of

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.



bursts of electrical current. When written, the code is represented by a series of 0's and 1's. This code is commonly referred to as the *binary code*.

Computer Control

How does a robotic arm know what movements 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, so do computers control the movement of robotic systems. The computer uses a series of instructions known as a *program*. Robotic programs are very complex. They must list in logical order all the steps needed for the robot to perform a task.

Imagine listing each command the brain sends to muscles when you pour milk from a container into a glass. Robotic software (program) designers prepare flowcharts that list the basic movements of the robot. These movements are then broken down into finer detail. They are then written in a language that computers can understand.

Computers send instructions to the actuators that power the movement of the joints. The instructions tell the robotic arm how far to travel, how much pressure to apply, and how to move a tool to perform a task. The instructions are sent as electrical signals that rotate stepper motors or open pneumatic valves, causing the pistons to travel.

Robotic programmers write the computer instructions or software to control the robotic hardware. Instructions

Linking to COMMUNICATION

Word Origins. The English language has taken words from many languages. In this chapter you learned that "robot" is a Czech word. With the help of your language arts teacher and/or librarian, compile a list of foreign words used commonly in English. Hint: Think of words associated with food, music, and clothing.

can be created by guiding the robotic arm through a sequence of movements and programming the computer to remember the pattern of motion. Teaching a robot in this manner is called *lead-through programming*. 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 know 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 to 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.

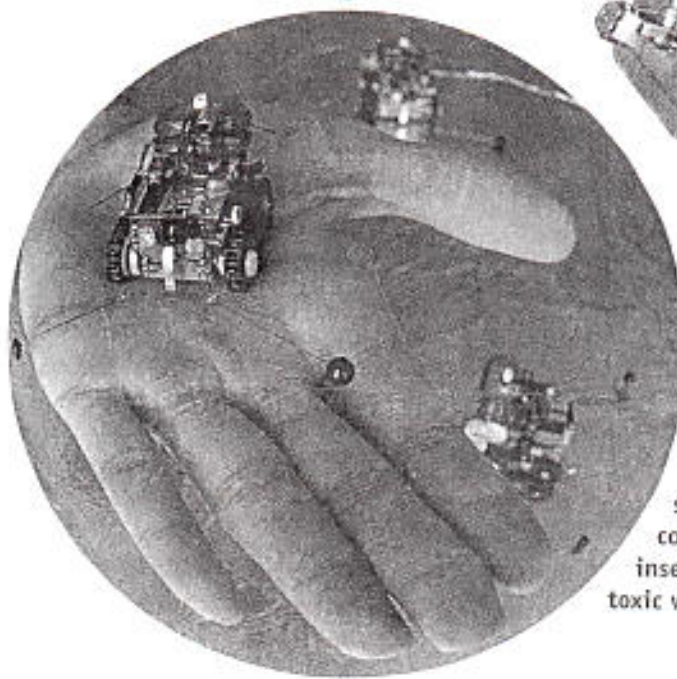
A CLOSER LOOK

Robots

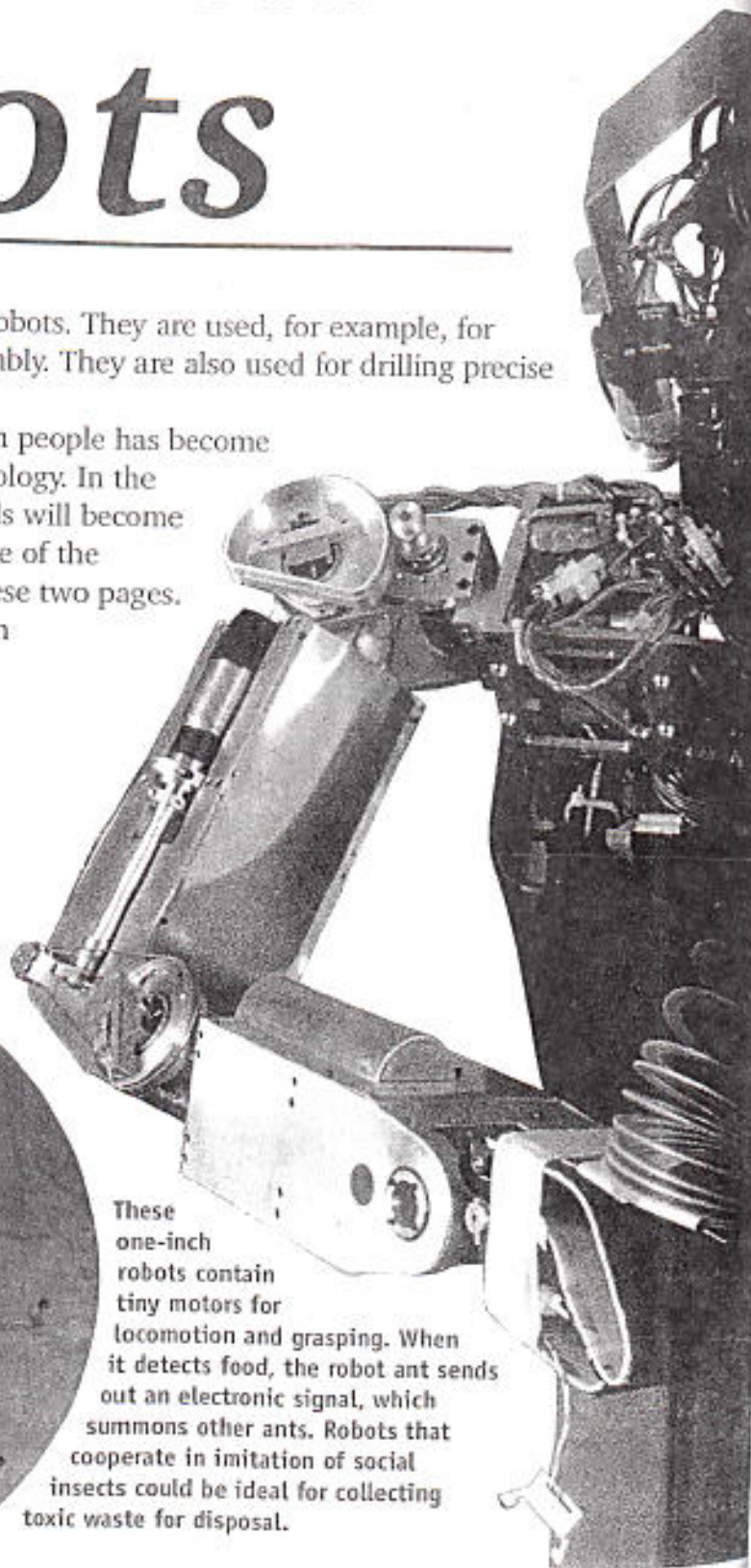
Some jobs are better done by robots. They are used, for example, for welding jobs in automobile assembly. They are also used for drilling precise holes in hip-replacement surgery.

The way machines interact with people has become an important dimension of technology. In the future, control by voice commands will become more widespread. Cog is the name of the humanoid robot shown across these two pages. It is programmed to mimic human movements and senses.

ROBOT ANTS

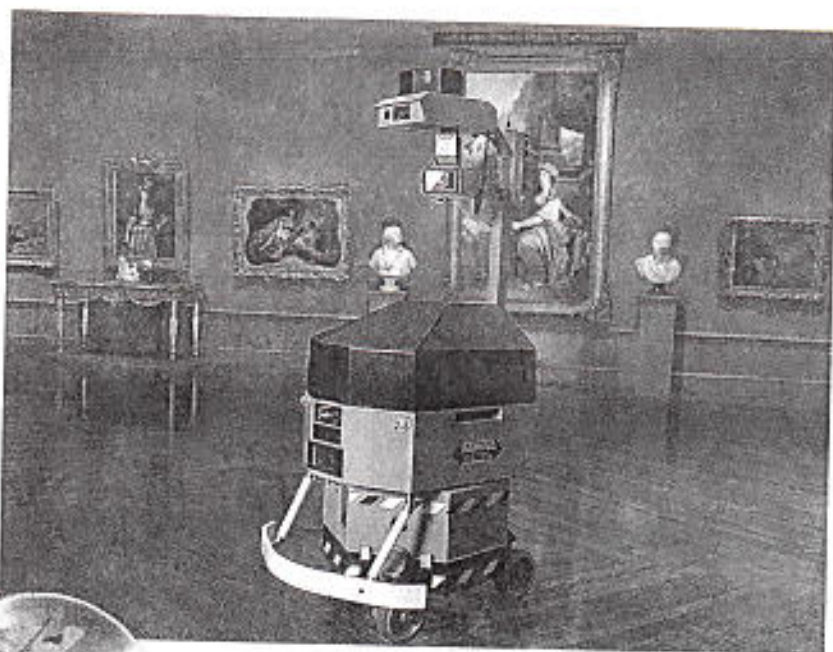


These one-inch robots contain tiny motors for locomotion and grasping. When it detects food, the robot ant sends out an electronic signal, which summons other ants. Robots that cooperate in imitation of social insects could be ideal for collecting toxic waste for disposal.



SECURITY ROBOT

This security robot is programmed with a detailed map of the museum it guards. Its detectors give warnings of smoke, fire, and increases in humidity. It can also detect movement.



ROVER SOJOURNER

This solar-powered robotic vehicle was used by NASA to study the composition of soil and rocks on Mars. Controlled by computer, it could steer itself to avoid obstacles. It provided regular location updates.

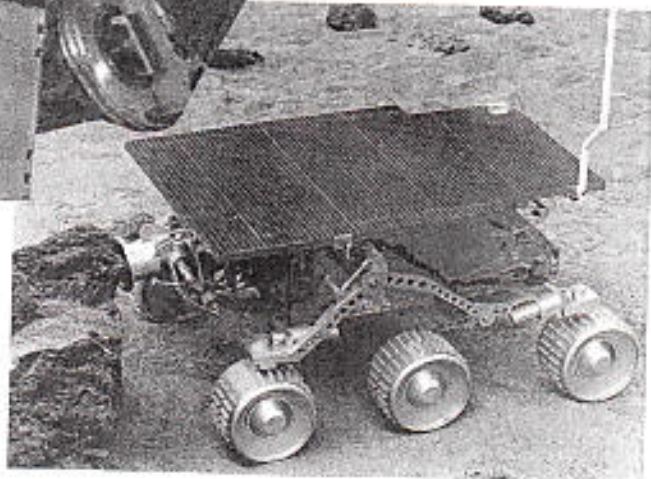
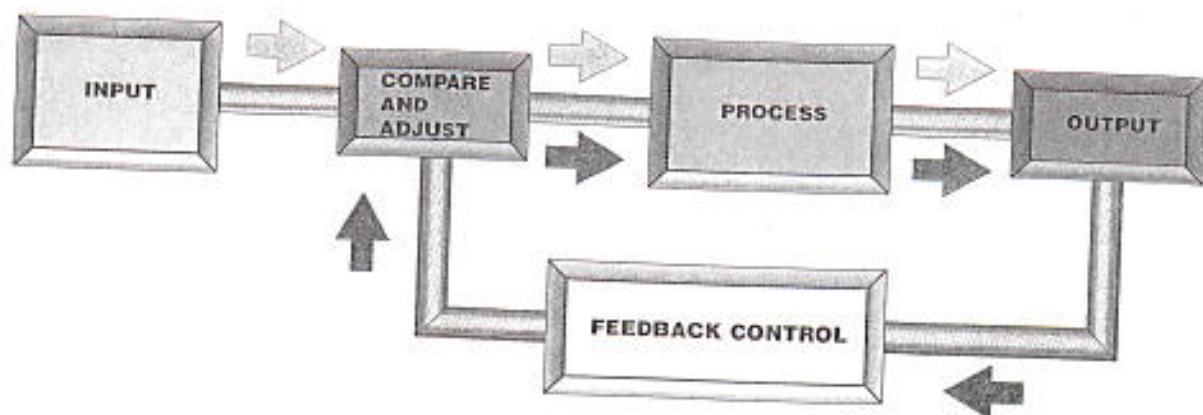


Fig. 17-8 The feedback control process. On robotic systems, sensors monitor what the system is actually doing. If the input to the system does not match the output from the system, the system is adjusted.



What if the handle is too hot? If the handle is too hot, signals quickly return to your brain. There they are translated as pain signals. 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 know where they are and to adjust their actions. 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 sensors known as contact sensors. These feed information back to the computer about a task it is working on. Contact sensors send electrical signals to the computer. The data might include information on the shape of an 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. Fig. 17-9.

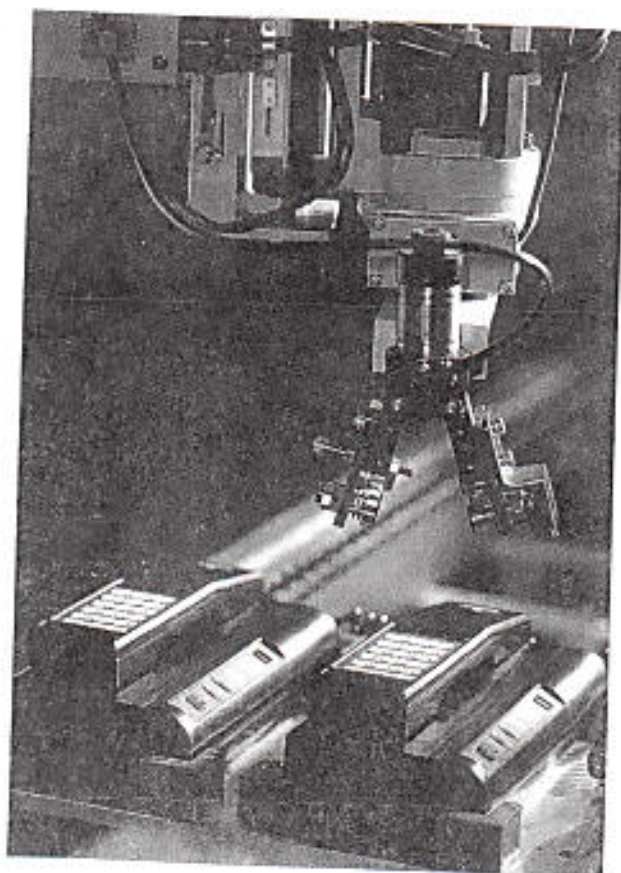


Fig. 17-9 Advances in computer control, electronics, and mechanics enable robots to perform more intricate work.

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

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 like welding and painting use angular or optical sensors. These track the

arm's movement. These sensors, which are shaped like disks, have markings. The disks are placed at each joint in the robotic arm. As the joint moves, optical scanners (like cameras) read the code. 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.

Probably the most famous robot arm, seen hard at work by millions of people, is the Remote Manipulator System (RMS) used aboard the Space Shuttle. Fig. 17-10. The RMS is a jointed robotic arm. It uses cameras and angle sensors to tell the

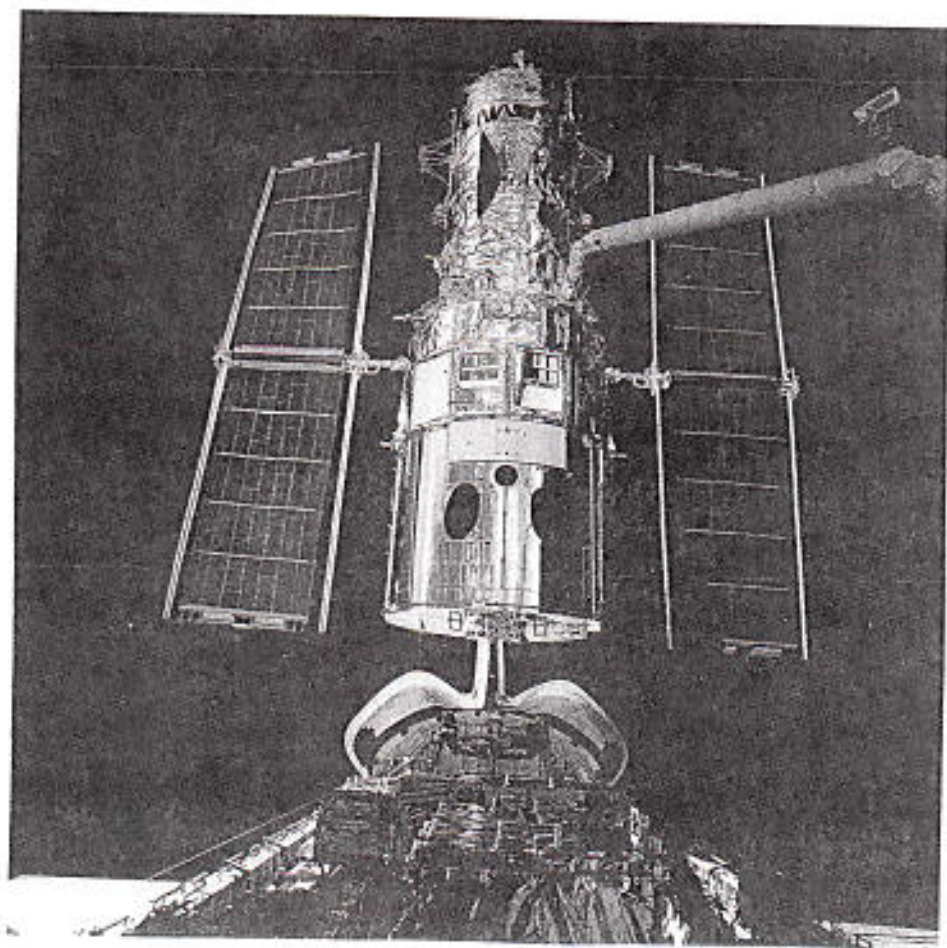


Fig. 17-10 In the darkness of space, the Hubble Space Telescope (HST) is lifted by the remote manipulator system (RMS) from its berth in the cargo bay of the Earth-orbiting Space Shuttle Discovery. The orbiter uses electric motors to position its robotic arm. Video cameras help astronauts view the arm as they manually move it towards its target.

FASCINATING FACTS

A robot known as Robodoc is used in hip replacement surgery. The robot drills a hole in the femur (thigh bone). Because Robodoc drills a perfect hole every time, the implant always fits perfectly.

computer its position. The arm can be used to release satellites into space as well as retrieve items already in orbit. The RMS can also serve as a remote work platform for doing repair work on space vehicles. Robots may also use microphones to sense sounds. They may use sonar to measure distances. They use sensors to detect poisonous materials in the work envelope. These sensors are called non-contact sensors.

Robot Generations

The first generation of robots was designed by industry to perform a variety of tasks. 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 tasks more complex than the tasks performed by early robots. Today's robots are flexible. Fig. 17-11. 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.

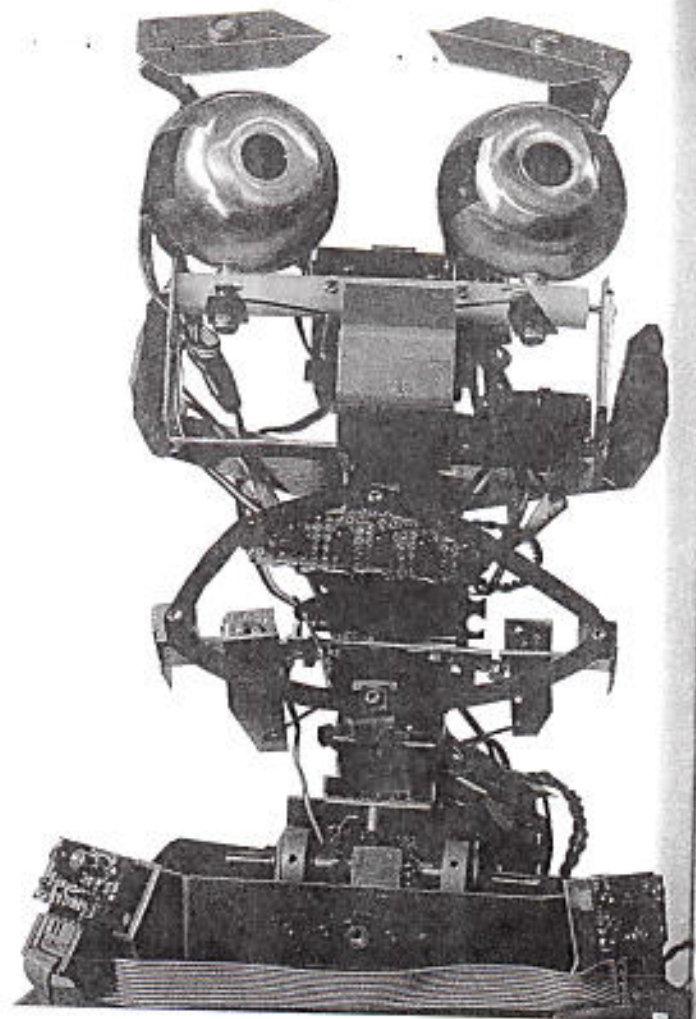


Fig. 17-11 IT (Interactive Technology), is demonstrated here as an interactive robot. It mimics the human emotions of happiness, sadness, surprise, boredom, sleepiness, and anger.

IMPACTS

Are there negative impacts to the use of robot technology?

What if your friend worked in a factory that assembled automobiles? She performs her job with the greatest accuracy and never misses work. Her supervisor often tells her that she is the most productive and reliable employee in the company. One day when your friend goes to work, she walks onto the assembly line floor to find a shiny robotic arm in her spot. The arm works twice as fast as your friend. It takes no breaks, and works twenty-four hours a day.

Your friend has just been displaced. "Displaced" is a term used to describe a person whose job has been taken over by automation or new technology. Many experts tell us that robotic technology may cause increased unemployment as companies switch to automation.

Others say that being displaced is not the same as being dismissed. Displaced

employees usually find new work within the same company or with other companies that are not yet automated.

THE FUTURE

The use of robots in business and industry is part of the automation revolution. Automation is the process by which computers control a series of tasks in manufacturing. Automated factories can operate with very few people. Automated machines can usually work faster, at lower cost, and more accurately than human workers. Remember that robots are not paid a salary, are never late, never call in sick, never need health insurance, and never take vacations.

Robotic automation now allows manufacturers to produce products more cheaply. This allows products to be sold for less. This allows the manufacturer to become more competitive in the world market. In the future, the use of robots will increase.

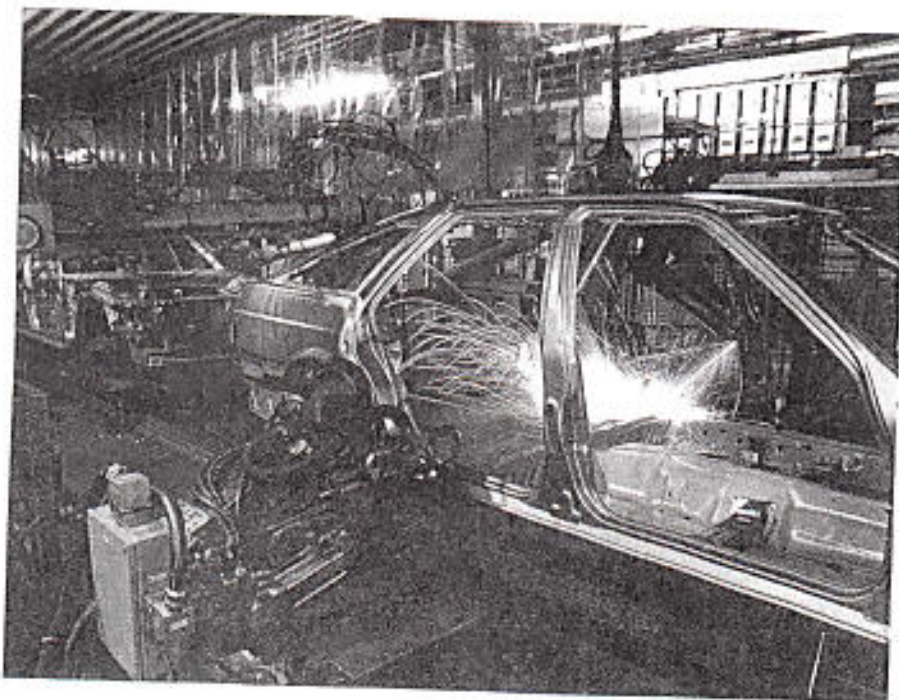


Fig. 17-12 Welding is commonly done by robots. Weld placement can be precisely controlled.

Apply What You've Learned

Design and Build a Pneumatic Control Device

State the Problem

Design and build a device that will convert the pneumatic force of the balloon's motion into linear (straight) or rotary (circular) motion.

Develop Alternative Solutions

Using the materials listed, design a device that can convert the pneumatic force of the balloon's expansion into linear or rotary motion. Sketch several.

Select the Best Solution

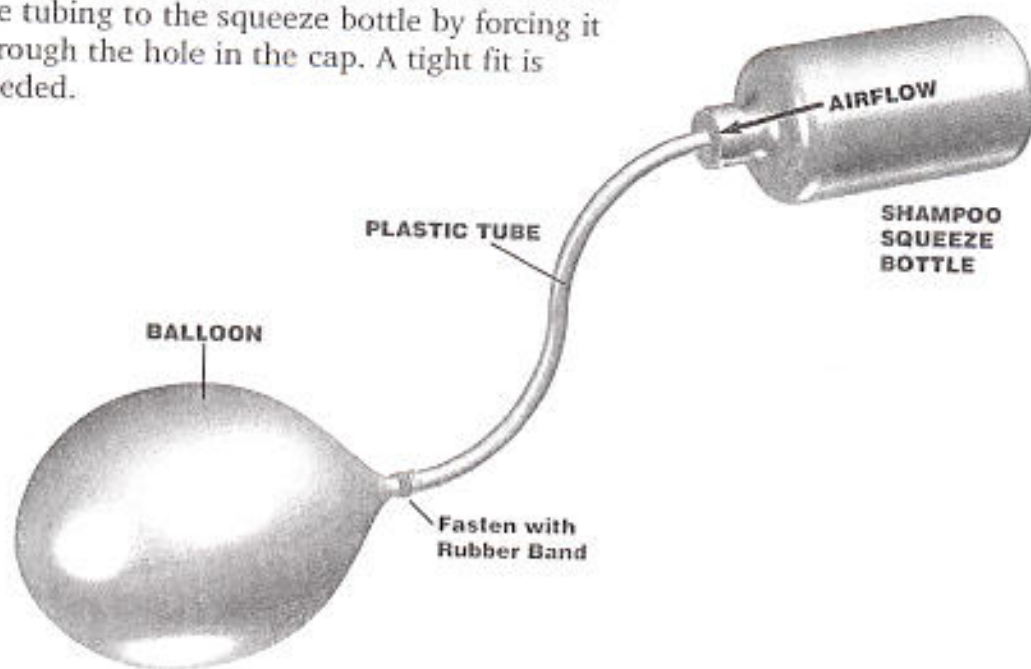
Choose the design that you think will be most effective.

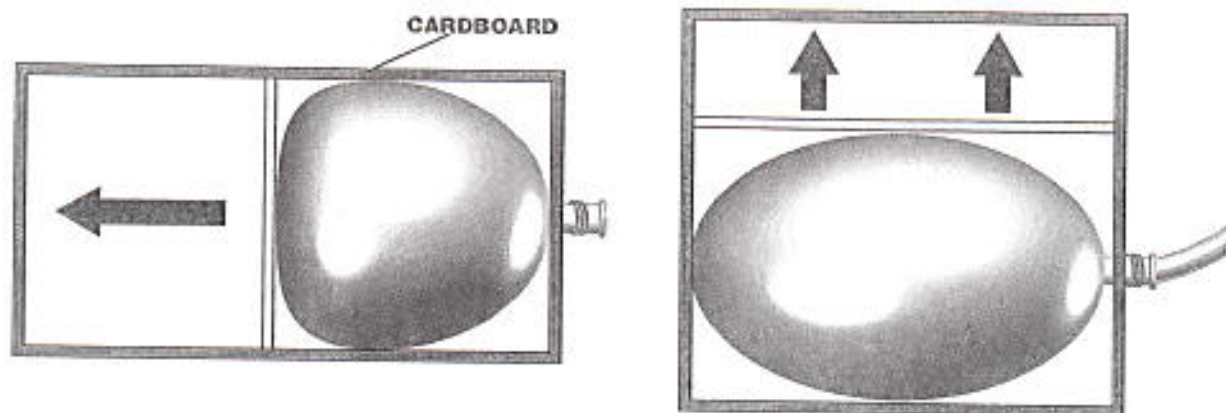
Implement the Solution

1. Attach the balloon to the plastic tubing, using a rubber band. Attach the other end of the tubing to the squeeze bottle by forcing it through the hole in the cap. A tight fit is needed.

Collect Materials and Equipment

1/4" plastic tubing
squeeze bottle
cardboard
dowels of assorted diameters
wood scraps
tape
glue
string
rubber bands
material processing equipment
balloon





2. Experiment with the pneumatic system. Get a feel for its power and how the balloon expands. Try lifting a stack of books.

Evaluate the Solution

1. In a real device, what mechanism would replace the balloon as a power source?
2. What effect would a larger squeeze bottle have on your system?
3. Make a sketch showing how the mechanism could be used as a gripper arm.
4. Explain what makes the balloon expand.
5. If the air in the bottle was replaced with water, what kind of system would it be?
6. Can you think of a use for your design? Can you find everyday devices that use a mechanism similar to yours? List them.

CAREERS IN

Robotics

ROBOTICS TECHNICIAN

Manufacturing firm needs robotics technician to program and monitor robotics equipment. Must be able to perform precise work and have knowledge of hydraulics, electronics, and programming. Post-high school training required. Responsible for setup, operation and preventative maintenance. Please send resume to: Southland Manufacturing Company, 7223 Heyward Drive, Lansing, IA 44208.

MAINTENANCE MECHANIC

Manufacturing firm has immediate opening on the evening shift for a maintenance mechanic with knowledge of circuit board functions. Responsible for locating and replacing faulty printed circuit boards in robot controller. Work in newly renovated facility. Salary plus overtime opportunities. Submit resume to: Personnel, Brooks Manufacturing, Inc., 70 Ackerman Place, Indianapolis, IN 52201.

MECHANICAL ENGINEER

Engineering firm needs mechanical engineer with background and knowledge in design. Work with engineering team to design and develop robots for use in production operations. Bachelor's degree is required. Will be actively involved in all phases of development. Excellent working conditions. Submit resume to: Robotics Engineering Design Group, 1313 Henderson Drive, Whittier, CA 90020.

INDUSTRIAL ROBOT OPERATOR

Experienced operator needed for first or second shift. Good working knowledge of MS-DOS and computer literacy a plus. Must be able to diagnose and solve problems without direct supervision. Fast-paced direct marketing company offers competitive wages and excellent benefits. Please send resume to Human Resources Manager, HKN Direct Marketing, 5590 Cass Avenue, Minneapolis, MN 41024.

SALES ENGINEER

Robotics company needs sales engineer to act as liaison between company engineers and sales and marketing staff. Responsible for training sales staff on products and applications and communicating new design ideas to engineering staff. A degree in engineering or computer science is required. Must have excellent communication skills to explain highly technical terminology. Forward resume to: Human Resources, Robotics International, 8820 Burlington Avenue, Greensboro, NC 34421.

Linking to the WORKPLACE

Have you considered a possible career? If you have, what jobs do you think a robot could perform in your workplace? Robots are designed to perform repetitive

tasks that require a high degree of accuracy. If you could have a robot perform three jobs for you every day, what would they be?

Chapter 17 Review

SUMMARY

- A robot is a machine made to act like a living thing.
- Robotics is the study of robots.
- The transistor and computer are important in robot technology.
- The space a robot moves within is known as its work envelope.
- The stepper motor is a common power source for robotic movement.
- Robots depend on feedback control, which allows them to adjust their actions.
- Uses for robots have expanded as technology has developed.

CHECK YOUR FACTS

1. In what ways are industrial robots similar to humans?
2. What important technological developments had to take place before computer control robotics 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 a variety of end effectors commonly used on robots and describe how they work.
7. Describe two ways a robot can be taught a task.
8. Explain how feedback control is used to adjust robotic movements.

CRITICAL THINKING

1. 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 that will be displaced by your actions.
2. Prepare a list of tasks usually performed by people in their home that could be done by robots.
3. Prepare sketches of a robotic arm that could be used to turn pages in a book for a disabled person. Label the parts.