25

BUILD A REVOLUTE COORDINATE ARM

The revolute coordinate arm design provides a great deal of flexibility, yet requires few components. The arm described in this chapter enjoys only two degrees of freedom. You'll find, however, that even with two degrees of freedom, the arm can do many things. It can be used by itself as a stationary pick-and-place robot, or it can be attached to a mobile platform. The construction details given here are for a left hand; to build a right hand, simply make it a mirror image of the left.

You'll note that the arm lacks a hand—a gripper. You can use just about any type of gripper. In fact, you can design the forearm so it accepts many different grippers interchangeably. See Chapter 27, "Experimenting with Gripper Designs," for more information on robot hands.

Design Overview

The design of the revolute coordinate arm is modeled after the human arm. A shaft-mounted shoulder joint provides shoulder rotation (degree of freedom #1). A simple swing-arm rotating joint provides the elbow flexion (degree of freedom #2).

You could add a third degree of freedom, shoulder flexion, by providing another joint immediately after the shoulder. In tests, however, I found that this basic two-degree-of-freedom arm is quite sufficient for most tasks. It is best used, however, on a mobile platform where the robot can move closer to or farther away from the object it's grasping. That's cheating, in a way, but it's a lot simpler than adding another joint.

Shoulder Joint and Upper Arm

The shoulder joint is a shaft that connects to a bearing mounted on the arm base or in the robot. Attached to the shaft is the drive motor for moving the shoulder up and down. The motor is connected by a single-stage gear system, as shown in Fig. 25.1 (refer to the parts list in Table 25.1). In the prototype arm for this book, the output of the motor was approximately 22 rpm, or roughly one-third of a revolution per second.

For a shoulder joint, 22 rpm is a little on the fast side. I chose a gear ratio of 3:1 to decrease the speed by a factor of three (and increase the torque of the motor roughly by a factor of three). With the gear system, the shoulder joint moves at about one revolution every eight seconds. That may seem slow, but remember that the shoulder joint swings in an arc of a little less than 50°, or roughly one-seventh of a complete circle. Thus, the shoulder will go from one extreme to the other in under two seconds.

Refer to Fig. 25.2. The upper arm is constructed from a 10-inch length of 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock and a matching 10-inch length of 41/64-inch-by-1/2-inch-by-1/16-inch aluminum channel stock. Sandwich the two stocks together to make a bar. Drill a 1/4-inch hole 1/2 inch from the end of the channel stock pieces. Cut a piece of 1/4-inch 20 all-thread rod to a length of seven inches (this measurement depends largely on the shoulder motor arrangement, but seven inches gives you room to make changes). Thread a 1/4-inch 20 nut, flat washer, and locking washer onto one end of the rod. Leave a little extra—about 1/8 inch to 1/4 inch—on the outside of the nut. You'll need the room in a bit.

Drill a 1/4-inch hole in the center of a 3 3/4-inch-diameter metal electrical receptacle cover plate. Insert the rod through it and the hole of the larger channel aluminum. Thread two 1/4-inch 20 nuts onto the rod to act as spacers, then attach the smaller channel aluminum. Lock the pieces together using a flat washer, tooth washer, and 1/4-inch 20 nut. The shoulder is now complete.

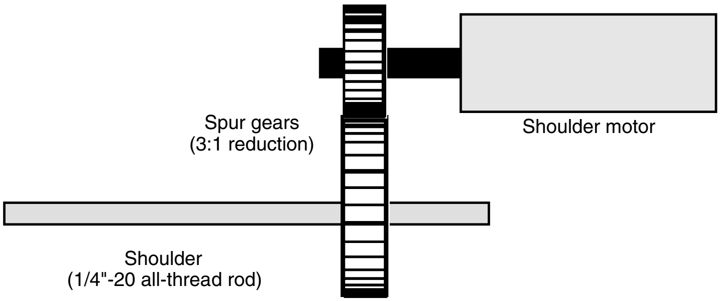

FIGURE 25.1 **The gear transfer system used to actuate the shoulder of the revolute arm. You can also use a motor with a built-in reduction gear if the output of the motor is not slow enough for the arm.**

Table 25.1 PARTS LIST FOR REVOLUTE ARM.

1	10-inch length 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock
1	10-inch length 41/64-inch-by-1/2-inch-by-1/16-inch aluminum channel stock
1	8-inch length 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock
1	8-inch length 41/64-inch-by-1/2-inch-by-1/16-inch aluminum channel stock
1	7-inch length 1/4-inch 20 all-thread rod
2	1 3/4-inch-by-10/24 stove bolt
2	1 1/2-inch-by-3/8-inch flat corner iron
1	3-inch-by-3/4-inch mending plate "T" (for motor mounting)
2	1/2-inch aluminum spacer
1	1/4-inch aluminum spacer
2	3/4-inch-diameter, 5-lugs-per-inch timing belt sprocket
1	20 1/2-inch-length timing belt (5 lugs per inch)
2	Stepper motors (see text)
1	3:1 gear reduction system (such as one 20-tooth 24-pitch spur gear and one 60-tooth 24-pitch spur gear)
Misc	6/32, 10/24, and 1/4-inch 20 nuts, washers, tooth lock washers, fishing tackle weights

Elbow and Forearm

The forearm attaches to the end of the upper arm. The joint there serves as the elbow. The forearm is constructed much like the upper arm: cut the small and large pieces of channel aluminum to eight inches instead of ten inches. Construct the elbow joint as shown in Figs. 25.3 and 25.4, using two 1 1/2-inch-by-3/8-inch flat corner angles, 1/2-inch spacers, and 10/24 hardware. The 3/4-inch timing belt sprocket (5 lugs per inch) is used to convey power from the elbow motor, which is mounted at the shoulder. The completed joint is shown in Fig. 25.5.

You can actually use just about any size of timing belt or sprocket. When using the size of sprockets specified in Table 25.1, the timing belt is 20 1/2 inches. If you use another size sprocket for the elbow or the motor, you may need to choose another length. You can adjust for some slack by mounting the elbow joint closer or farther to the end of the upper arm.

You may also use #25 roller chain to power the elbow. Use a sprocket on the elbow and a sprocket on the motor shaft. Connect the two with a #25 roller chain. You'll need to experiment based on the size of sprockets you use to come up with the exact length for the roller chain.

When the elbow and forearm are complete, mount the motor on the shoulder, directly on the plate cover. The motor we chose for the prototype revolute coordinate arm was a

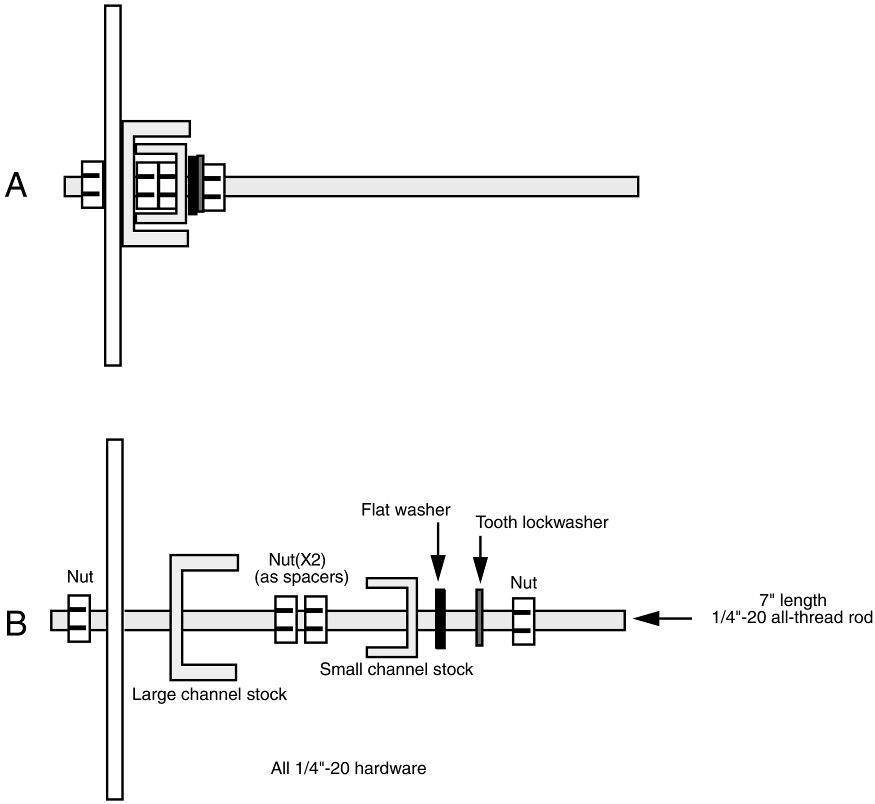

FIGURE 25.2 **Shoulder shaft detail. *a.* Completed shaft; *b.* Exploded view.**

one-amp medium-duty stepper motor. Predrilled holes on the face of the motor made it easier to mount the arm. A 3-inch-by-3/4-inch mending plate T was used to secure the motor to the plate, as illustrated in Fig. 25.6. New holes were drilled in the plate to match the holes in the motor (1 7/8-inch spacing), and the "T" was bent at the cross.

Unscrew the nut holding the cover plate and upper arm to the shaft, place the "T" on it, and retighten. Make sure the motor is perpendicular to the arm. Then, using the other hole in the "T" as a guide, drill a hole through the cover plate. Secure the T in place with an 8/32 by 1/2-inch bolt and nut. The finished arm, with a gripper attached, is shown in Fig. 25.7.

Refinements

As it is, the arm is unbalanced, and the shoulder motor must work harder to position the arm. You can help to rebalance the arm by relocating the shoulder rotation shaft and by adding counterweights or springs. Before you do anything hasty, however, you may want to attach a gripper to the end of the forearm. Any attempts to balance the arm now will be

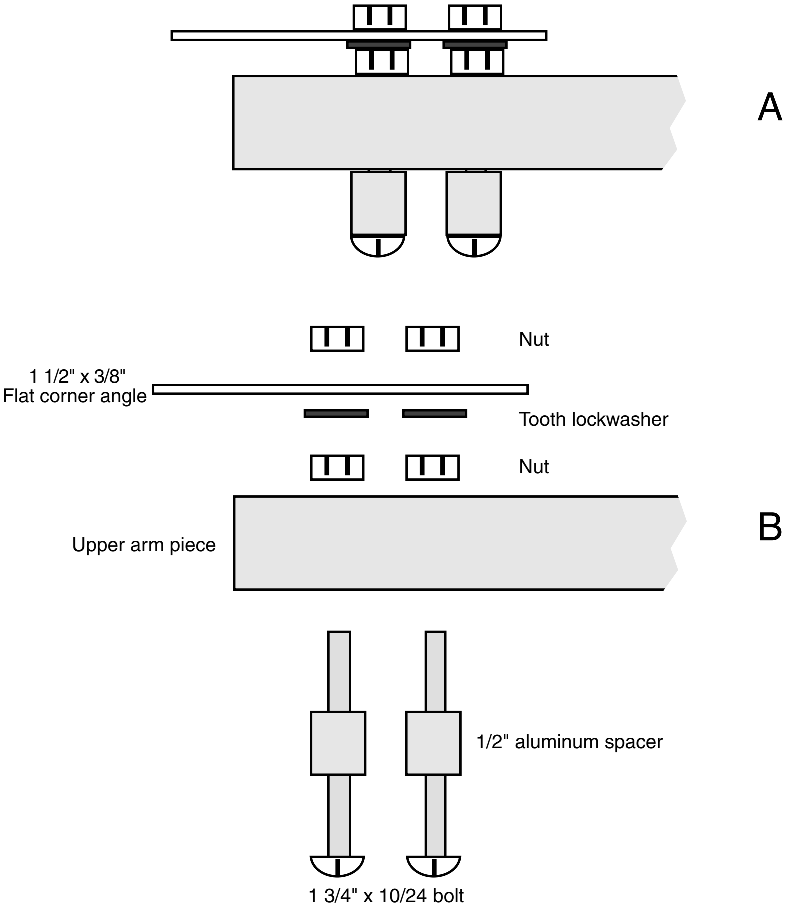

FIGURE 25.3 **Upper arm elbow joint detail. *a.* Complete joint; *b.* Exploded view.**

severely thwarted when you add the gripper.

The center of gravity for the whole arm, with the elbow drive motor included, is approximately midway along the length of the upper arm (at least this is true of the prototype arm; your arm may be different). Remove the long shaft from the present shoulder joint, and replace it with a short 1 1/2-inch- or 2-inch-long 1/4-inch 20 bolt. Drill a new 1/4-inch hole through the upper arm at the approximate center of gravity, and thread the shoulder shaft through it. Attach it as before, using 1/4-inch 20 nuts, flat washers, and toothed lock washers.

The forearm is also out of balance, and you can correct it in a similar manner, by attaching the shoulder joint nearer to the center of the arm. This has the unfortunate side effect, however, of shortening the reach of the forearm. One solution is to make the arm longer to compensate. In effect, you'll be keeping the elbow joint where it is, just adding extra length

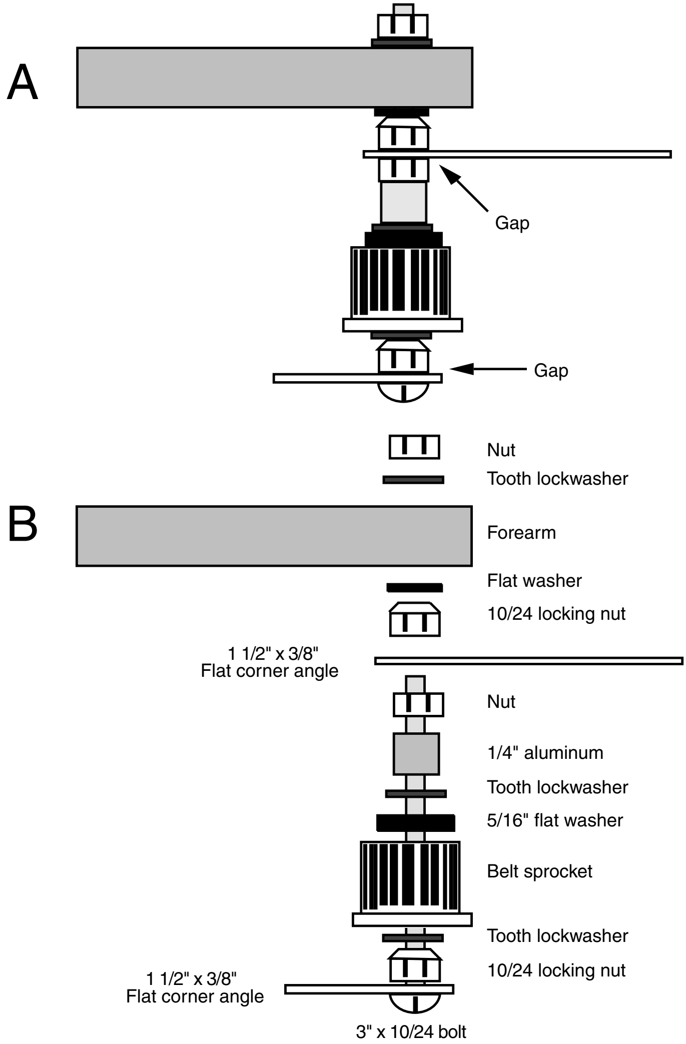

FIGURE 25.4 **Forearm elbow joint detail. *a.* Complete joint; *b.* Exploded view.**

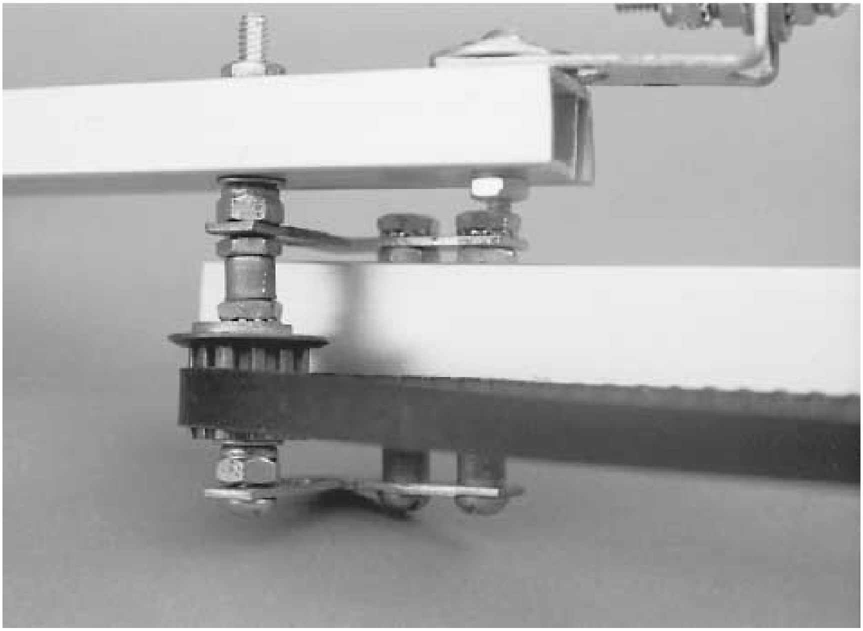

FIGURE 25.5 **A close-up view of the elbow joint.**

behind it.

This may interfere with the operation of the arm or robot, however, so you may want to opt for counterweights attached to the end of the arm. I successfully used two four-ounce fishing tackle weights attached to the arm with a 2-inch-by-3/4-inch corner angle bracket (see Fig. 25.8).

Position Control

The stepper motors used for the shoulder and elbow joints of the prototype provide a natural control over the position of the arm. Under electronic control, the motors can be commanded to rotate a specific number of steps, which in turn moves the upper arm and forearm a specified amount.

You should supplement the open-loop servo system with limit switches. These switches provide an indication when the arm joints have moved to their extreme positions. The most common limit switches are small leaf switches. You can also construct optical switches using photo-interrupters. A small patch of plastic or metal interrupts the flow of light between an LED and phototransistor, thus signaling the limit of movement. You can build these interrupters by mounting an infrared LED and phototransistor on a small perforated board or purchase ready-made modules (they are common surplus finds).

When using continuous DC motors, you need to provide some type of feedback to

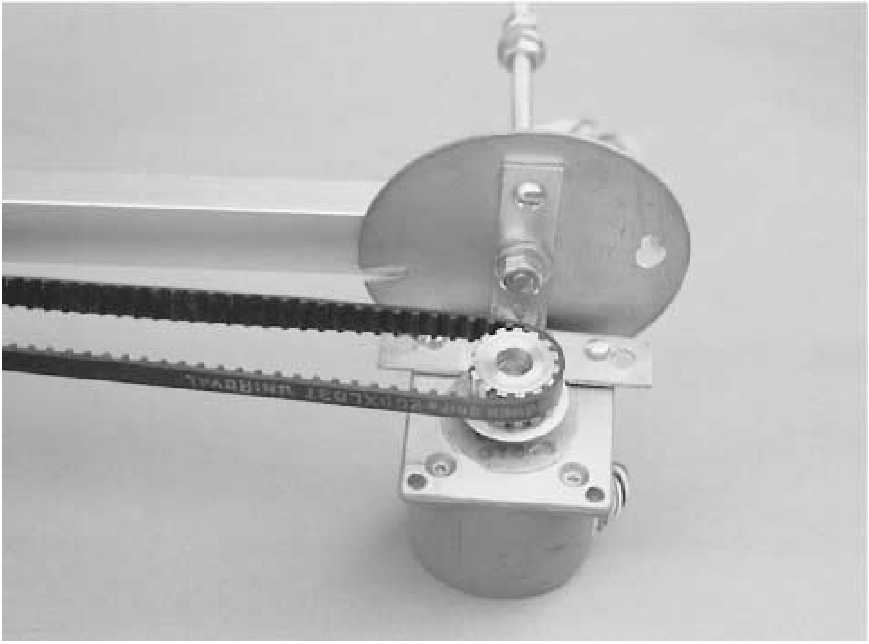

FIGURE 25.6 The motor mounted on the shoulder.

FIGURE 25.7 The completed arm, with gripper (hand) attached.

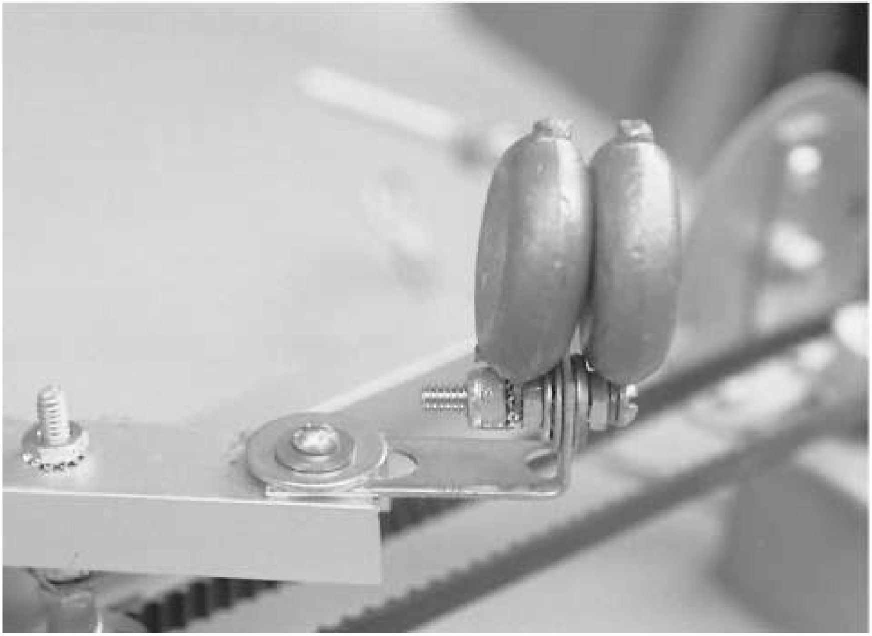

FIGURE 25.8 **Counterbalance weights attached to the end of the forearm help redistribute the weight. You can also use springs, which will help reduce the overall weight of the arm.**

report the position of the arm. Otherwise, the control electronics (almost always a computer) will never know where the arm is or how far it has moved. There are several ways you can provide this feedback. The most popular methods are a potentiometer and an incremental shaft encoder.

POTENTIOMETER

Attach the shaft of a potentiometer to the shoulder or elbow joint or motor (see Fig. 25.9), and the varying resistance of the pot serves as an indication of the position of the arm. Just about any pot will do, as long as it has a travel rotation the same as or greater than the travel rotation of the joints in the arm. Otherwise, the arm will go past the internal stops of the potentiometer. Travel rotation is usually not a problem in arm systems, where joints seldom move more than 40° or 50°. If your arm design moves more than about 270°, use a multiturn pot. A three-turn pot should suffice.

Another method is to use a slider-pot. You operate a slider-pot by moving the wiper up and down, rather than by turning a shaft. Slider-pots are ideal when you want to measure linear distance, like the amount of travel (distance) of a chain or belt. Fig. 25.10 shows a slider-pot mounted to a cleat in the timing belt used to operate the elbow joint.

The value of the pot is a function of the control electronics you have hooked up to it, but 10K to 100K potentiometers usually work well with most any circuit. The potentiome-

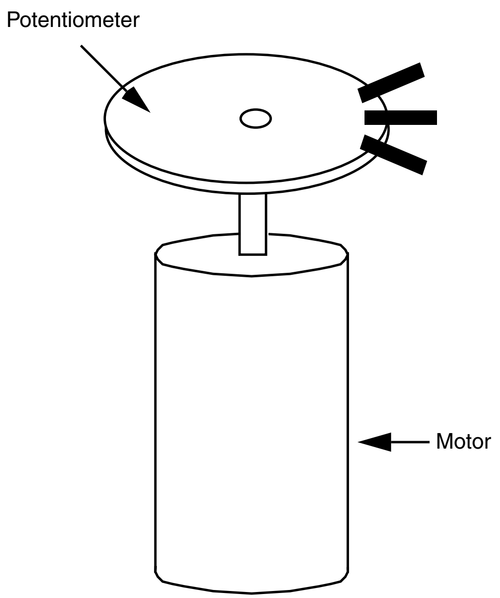

FIGURE 25.9 Using a potentiometer as a position feedback device. Mount the potentiometer on a drive motor or on a joint of the arm.

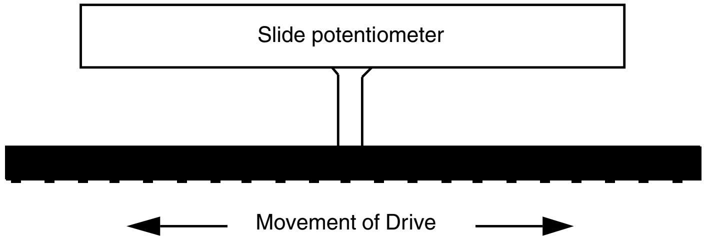

FIGURE 25.10 Using a slide potentiometer to register position feedback. The wiper of the pot can be linked to any mechanical device, like a chain or belt, that moves laterally.

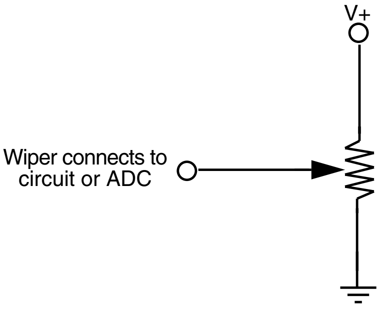

FIGURE 25.11 **The basic electrical hookup for providing a varying voltage from a potentiometer.**

ter may provide a relative measurement of the position of the arm, but the information is in analog form, as a resistance or voltage, neither of which can be directly interpreted by a computer.

By connecting the pot as shown in Fig. 25.11, you gain an output that is a voltage between 0 and the positive supply voltage (usually 5 or 12 volts). The wiper of the pot can be connected to the input of an analog-to-digital converter (ADC), which translates voltage levels into bytes.

Now, before you go off screaming about the complexity of ADCs, you should really try one first. The latest chips are relatively inexpensive (under $5) and require a very minimum number of external components to operate. The best part about ADC chips is that most have provisions for connecting eight or more analog signals. You select which signal input you want to convert into digital data. That means you can use one $5 ADC for all of the joints in a two-arm robot system.

To be useful, the ADC should be connected to a microprocessor or computer. You can also use your personal computer as the controlling electronics for your robot. Read Chapter 29, "Interfacing with Computers and Microcontrollers," for more information about ADCs and computer control.

Also note that some microcontrollers have their own ADCs built in. For example, the BasicX-24 from NetMedia sports eight ADC inputs; the OOPic microcontroller offers a pair of ADC inputs. Neither of these microcontrollers requires any external components to be connected to the ADC inputs. See Chaps. 32 and 33, respectively, for more information on the BasicX and OOPic microcontroller chips.

INCREMENTAL SHAFT ENCODER

The incremental shaft encoder was first introduced in Chapter 18, "Working with DC Motors." The shaft encoder is a disc that has many small holes or slots near its outside circumference. You attach the disc to a motor shaft or the shoulder or elbow joint. See Chapter 18 for more information on using shaft encoders. To review, shaft encoders are typically composed of a circuit connected to the phototransistor (the latter of which is baffled to block off ambient light). The phototransistor counts the number of on/off flashes and then converts that number into distance traveled. For example, one on/off flash may equal a 2° movement of the joint. Two flashes may equal a 4° movement, and so forth.

The advantage of the incremental shaft encoder is that its output is inherently digital. You can use a computer, or even a simple counter circuit, to simply count the number of on/off flashes. The result, when the movement ends, is the new position of the arm.

From Here

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Using stepper motors to drive robot parts	Chapter 19, "Working with Stepper Motors"
Different robotic arm systems and assemblies	Chapter 24, "An Overview of Arm Systems"
Attaching hands to robotic arms	Chapter 27, "Experimenting with Gripper Designs"
Interfacing feedback sensors to computers and microcontrollers	Chapter 29, "Interfacing with Computers and Microcontrollers"