

## BUILD A POLAR COORDINATE ARM

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**P**olar coordinate arms are ideal for use in a stand-alone robotic manipulator. They are fairly inexpensive and easy to build, and they can be adapted to a number of useful applications, especially robotic training. The design described in this chapter is a three-degree-of-freedom polar coordinate arm that is mounted on a stationary base. You can, if you wish, attach the arm to a mobile base or, for an even more outrageous project, add wheels or track to the base itself and make a giant rolling arm.

The arm design presented here has no gripper, or hand, mechanism. You can attach any number of different grippers to the end of the arm. Choose the gripper based on the application you have in mind. Read more about robotic grippers in Chapter 27, “Experimenting with Gripper Designs.”

### Constructing the Base

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The base measures 10 inches by 12 inches by 4 inches. The prototype for this book was made from aluminum shelving standards. Refer to Fig.26.1. You can also use 41/64-inch-by-1/2-inch-by-1/16-inch aluminum channel stock, which is recommended. Construct the base by cutting four 10-inch and four 12-inch lengths. Cut each end at a 45° angle. Cut four 2 1/2-inch riser pieces. Do not miter the ends of these lengths. Assemble the top and

bottom frames using 1 1/2-inch-by-3/8-inch flat corner angles. Secure the stock to the corner angles with 8/32 by 1/2-inch bolts and 8/32 nuts.

Refer to Fig. 26.2. Attach a 1-inch-by-1/2-inch corner angle bracket using 8/32 by 1/2-inch bolts and nuts to each one of the short riser pieces. Attach 2-inch-by-1/2-inch flat mending plates to the top of the riser pieces. Connect the top and bottom frames with the risers spaced 2 3/4 inches from the corners. Use 8/32 by 1/2-inch bolts and 8/32 nuts.

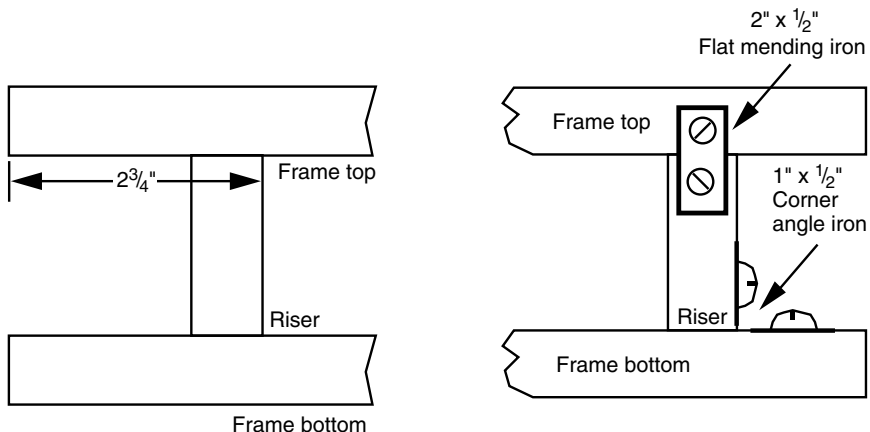
## Shoulder Rotation Mechanism

The shoulder rotation mechanism consists of a motor, a turntable, and a roller chain gear system. Start by adding a cross brace to the top of the base. Cut a 10 5/8-inch length of 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock. Mount it lengthwise in the center base using two 2 1/2-inch-by-1/2-inch flat mending iron Ts. Use 8/32 by 1/2-inch bolts and 8/32 nuts to secure the Ts and cross brace into place.

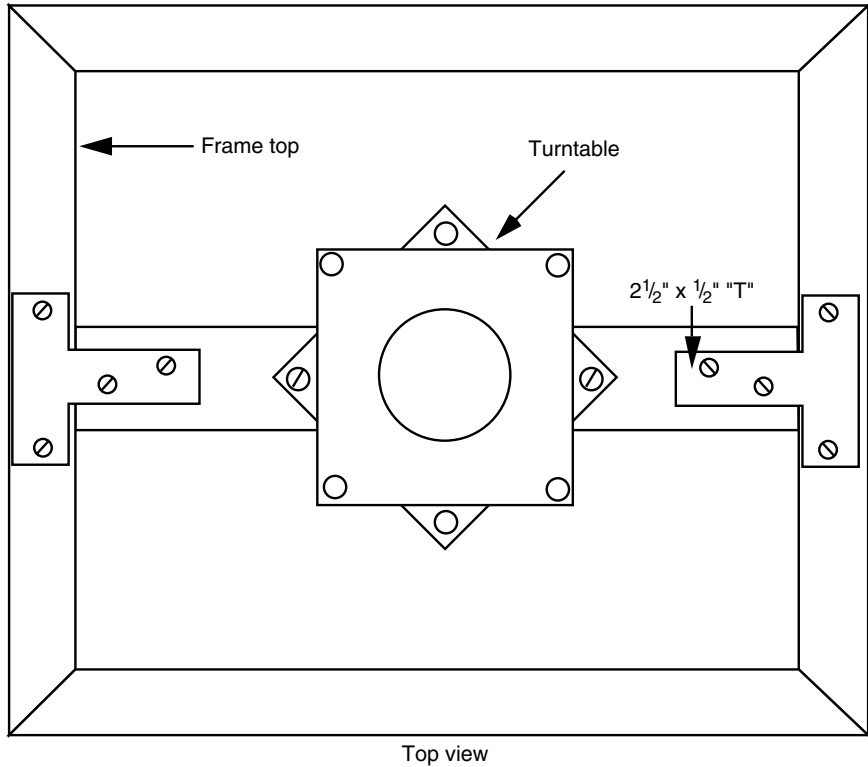
Drill a 3/8-inch hole in the center of the cross brace. Position one 3-inch-diameter ball-bearing turntable (lazy Susan) over the hole. Using the mounting holes on the baseplate of the turntable as a guide, mark corresponding mounting holes in the cross brace. Drill for 6/32 bolts (#28 bit) and attach the turntable using two 6/32 by 1/2-inch bolts and 6/32 nuts (see Fig. 26.3).

Construct the center shaft of the arm with a 3-inch-by-10/24 pan-head stove bolt. Place a 1/2-inch-diameter bearing on either side of the channel stock. Be sure the center (rotating part) of the bearings rest over the hole, or they won't turn properly, and that the head of the bolt is positioned over the inner wheel of the bearing. Add a 1/4-inch spacer and lock the assembly into place with a 10/24 nut.

On to the drive mechanics. The drive sprocket (35 teeth, 3-inch diameter, #25 roller chain) is sandwiched between two plastic spacers, as shown in Fig. 26.3. These spacers are actually closet pole holders. They already have holes drilled in the center; so you can just



**FIGURE 26.1** Cutting and assembly for the polar arm base risers. *a.* Riser placement; *b.* Hardware assembly detail.



**FIGURE 26.2** Cutting and assembly detail for crosspiece and turntable.

**TABLE 26-1 PARTS LIST FOR POLAR COORDINATE ARM.**

<i>Frame/BASE</i>	
4	12-inch lengths 41/64-inch-by-1/2-inch-by-1/16-inch aluminum channel stock
4	10-inch lengths 41/64-inch-by-1/2-inch-by-1/16-inch aluminum channel stock
4	2 1/2-inch lengths 41/64-inch-by-1/2-inch-by-1/16-inch aluminum channel stock
4	2-inch-by-1/2-inch flat mending iron
4	1-inch-by-1/2-inch corner angle iron
8	1 1/2-inch-by-3/8-inch flat corner angle iron
Misc	8/32 stove bolts, nuts, tooth lock washers
<i>Shoulder Base</i>	
1	10 5/8-inch length 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock
1	9-inch length 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock

TABLE 26.1 PARTS LIST FOR POLAR COORDINATE ARM. (Continued)

*Shoulder Base*

2	7-inch length 5/8-inch-by-9/16-inch-by-1/16-inch aluminum channel stock
2	2 1/2-inch mending plate "T"
2	1 1/4-inch-by-5/8-inch corner angle iron
1	3-inch-diameter ball-bearing turntable
1	3-inch-by-10/24 stove bolt, nuts, flat washers, tooth lock washers
2	Plastic closet pole holders
2	1/2-inch bearings
1	1/2-inch aluminum spacer
1	3-inch-diameter 35-tooth chain sprocket (#25 chain)
1	Stepper motor
1	1 3/4-inch-diameter 20-tooth chain sprocket (#25 chain)
1	17-inch-long (nominal) #25 roller chain
Misc	1/2-inch-by-8/32 stove bolts, nuts, tooth lock washers

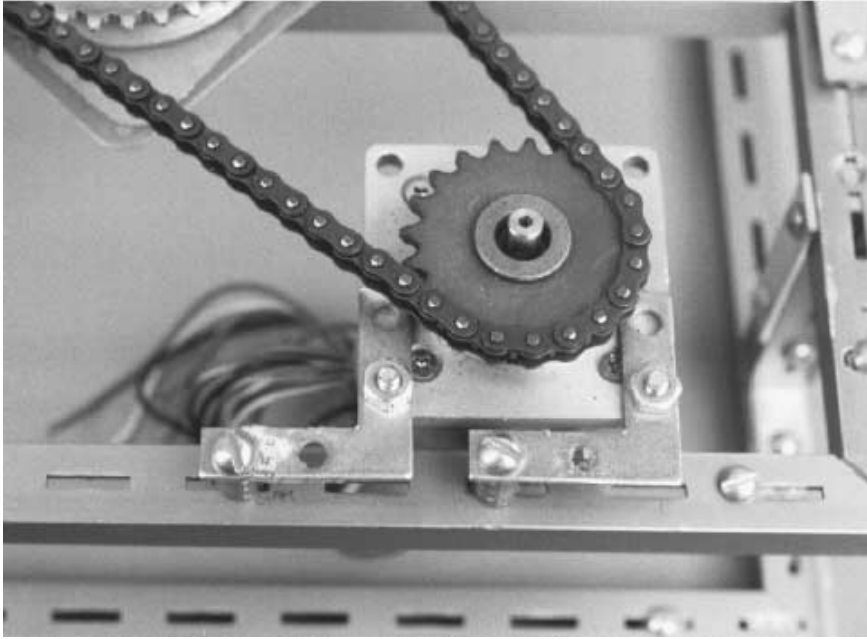
*Elbow*

2	6-inch lengths 5/8-inch-by-9/16-inch-by-1/16-inch aluminum channel stock
2	3 1/2-inch lengths 1-inch-by-1-inch-by-1/16-inch aluminum angle stock
1	2 1/2-inch length 1-inch-by-1-inch-by-1/16-inch aluminum angle stock
1	7 1/2-inch length 1/4-inch 20 all-thread rod, nuts, locking nuts, flat washers, tooth lock washers
2	1 3/4-inch-diameter 20-tooth chain sprocket (#25 chain)
1	17-inch-long #25 roller chain
1	Stepper motor
Misc	1/2-inch-by-8/32 stove bolts, nuts, tooth lock washers

*Forearm*

1	16-inch-long (nominal) drawer rail
2	1-inch-to-1 1/2-inch-diameter spur gears, with setscrew recessed in hub
1	3 1/2-inch length 1-inch-by-1-inch-by-1/16-inch aluminum angle stock
1	18-inch length (approx.) 1/16-inch diameter steel aircraft cable
2	14–16 gauge wire lug
1	Stepper motor
Misc	8/32 stove bolts, nuts, tooth lock washers





**FIGURE 26.4** The mounted shoulder motor, with chain sprocket and roller chain.

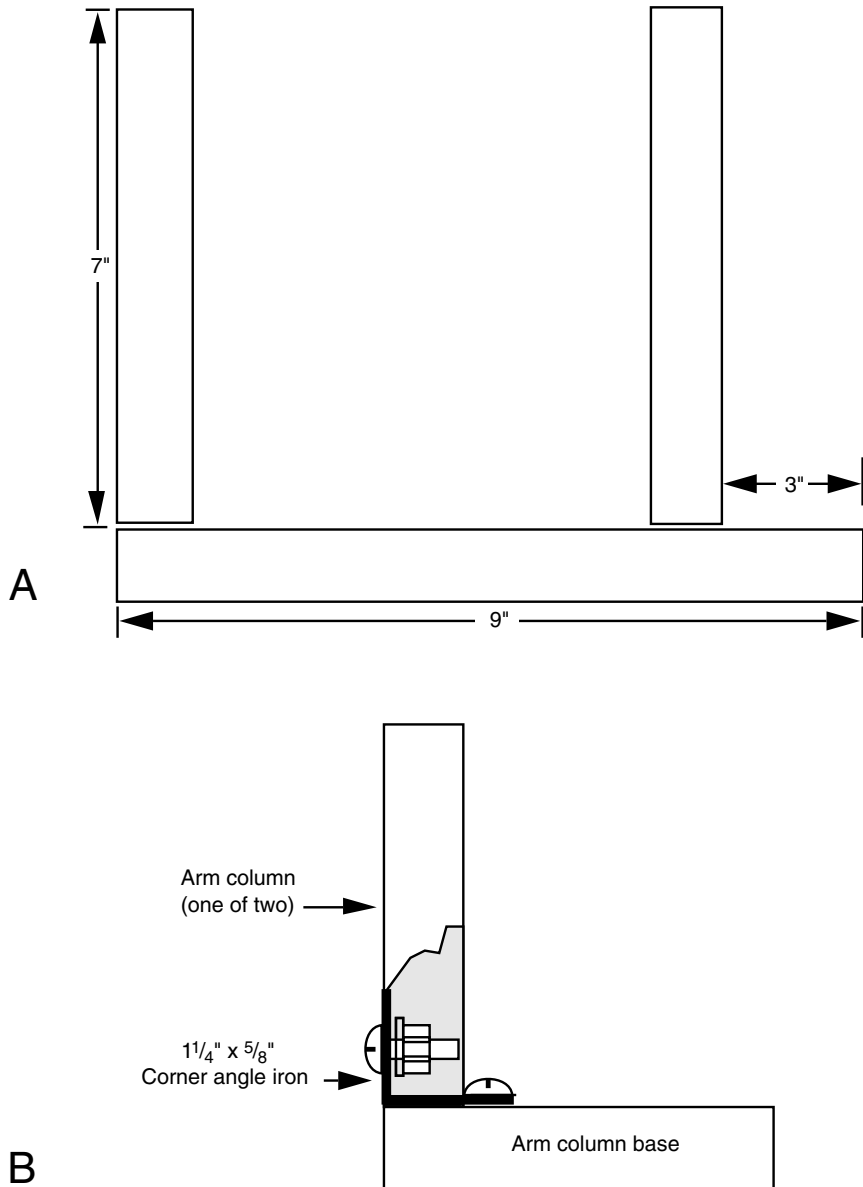
slightly longer or shorter length of roller chain because you can position the motor anywhere along the length of the frame to compensate.

Choose a mounting location with the roller chain in place. Move the motor along the edge of the frame until the chain is taut (but not overly tight), and mark the mounting location. At the mark, attach the motor to the frame using two 1 1/2-inch-by-3/8-inch flat corner braces. Elevate the braces using 1/2-inch spacers. Use 6/32 by 1/2-inch bolts and nuts to secure the motor to the braces and 8/32 by 1/2-inch bolts and nuts to secure the braces to the frame.

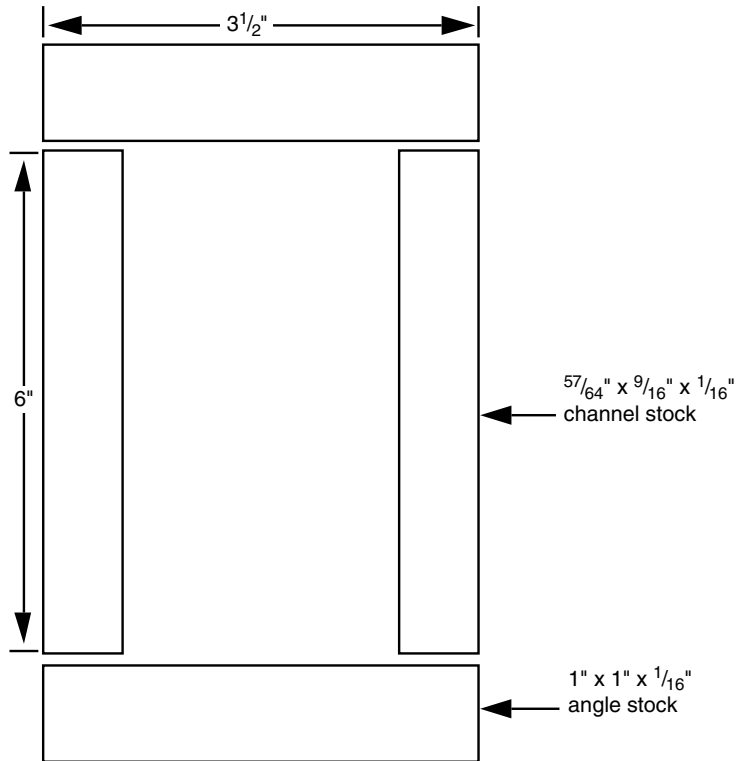
Construct the arm column using two 7-inch lengths of 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock and one 9-inch length of the same. Mount a 7-inch length flush to one end of the 9-inch member. Use 1 1/4-inch-by-5/8-inch corner angle brackets and 8/32 by 1/2-inch bolts and nuts to secure the pieces in place. Mount the other 7-inch length 3 inches from the opposite end of the 9-inch member (see Fig. 26.5 for details). Likewise, secure it using an angle bracket. Drill a 1/4-inch hole in the center of the 9-inch piece, and mount the assembly on the shoulder rotation shaft, as shown in the figure.

## Building the Elbow Mechanism

The elbow mechanism consists of a platform driven by a stepper motor. To distribute the weight, mount the motor on the 9-inch shoulder member. Refer to Fig. 26.6. Construct the



**FIGURE 26.5** Cutting and assembly for the arm column. *a.* Dimensions of pieces; *b.* Hardware assembly detail.



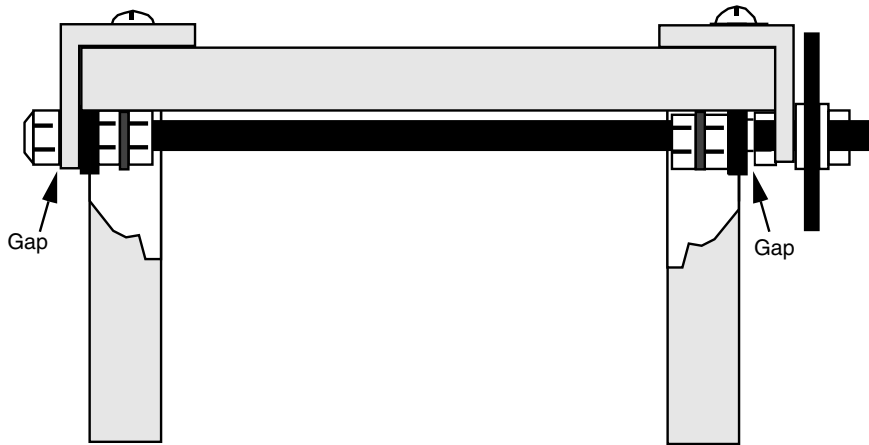
**FIGURE 26.6** Cutting detail for the elbow shaft.

elbow platform by cutting two 6-inch lengths of 57/64-inch-by-9/16-inch-by-1/16-inch aluminum channel stock. Couple them together with two 3 1/2-inch lengths of 1-inch-by-1-inch-by-1/16-inch aluminum angle stock. Connect the pieces using 1/2-inch-by-8/32 bolts and 8/32 nuts.

Drill a 1/4-inch hole in the center of each angle stock for the elbow rotation shaft. Cut a 7 1/2-inch length of 1/4-inch 20 all-thread rod and attach a locking nut to one end. Drill a 1/4-inch hole 1/2-inch down from the top of each 7-inch arm column piece. Thread the elbow rotation shaft through the pieces, using the hardware noted in Fig. 26.7. Secure a 20-tooth, 1 1/2-inch diameter #25 chain sprocket to the end.

Mount a matching 20-tooth #25 chain sprocket on the shaft of the elbow stepper motor (it is the same type as the one used for shoulder rotation). Attach a 17-inch length of #25 roller chain between the two sprockets, and mount the motor to the end of a 9-inch shoulder cross brace using a 2 1/2-inch length of 1-inch-by-1-inch-by-1/16-inch aluminum angle stock. Use 6/32 by 1/2-inch bolts and nuts to secure the motor to the angle stock. The angle stock is riveted to the cross brace (the head of a machine bolt is too thick). The motor, as attached, should look like the one in Fig. 26.8.





Sideview

A

**FIGURE 26.7** Assembly detail for the elbow shaft. *a.* Assembled shaft. (See p. 398 for an exploded view.)

## Building the Forearm

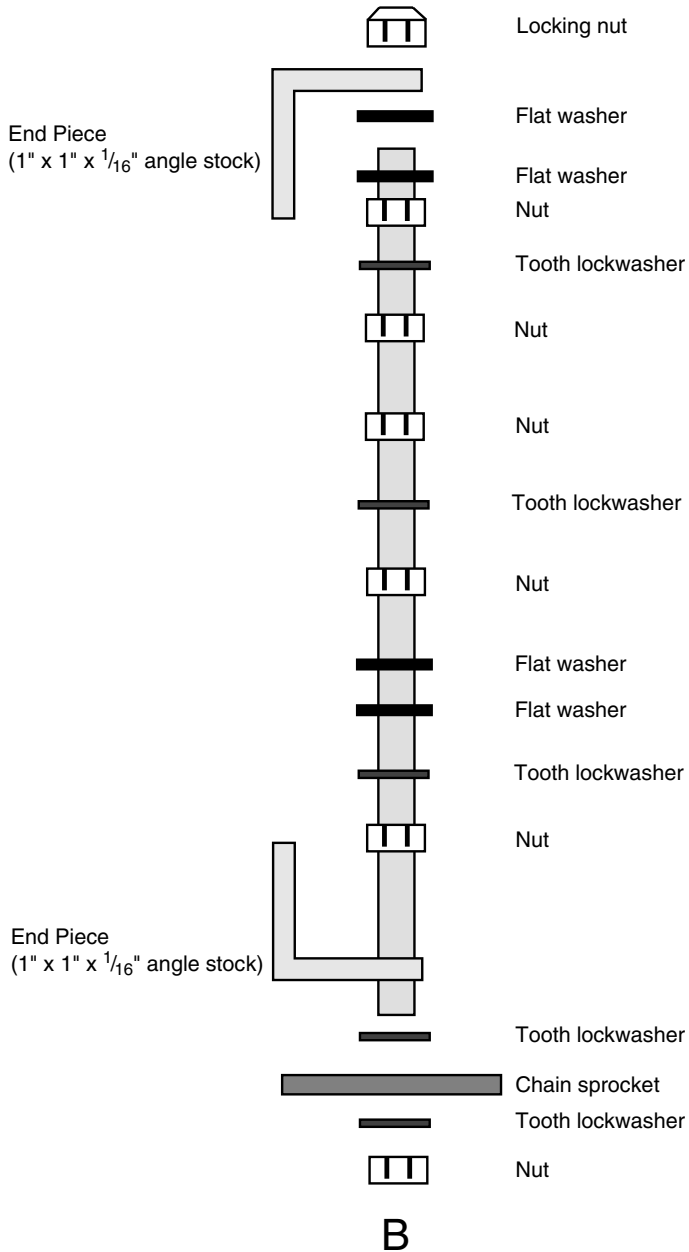
The retractable forearm is a rather simple mechanism, but you must exercise some patience when constructing it. The forearm uses commonly available parts, and to make your job easier you may want to stick with the parts specified in this chapter. No sense in both of us sweating this one out.

The retractable forearm is constructed using a metal drawer rail. The rail, shown in Fig. 26.9, is composed of two pieces: an 11-inch “base” and a 16 3/4-inch long retracting rail. The rail rides within the base on a set of ball bearings. If you add a little bit of grease, the rail slides smoothly along the length of the rail without trouble. The drawer rail used in the prototype required no modification, but some rails have stops and locks that you may want to defeat. Usually, this involves nothing more than filing down a piece of metal or drilling out the offending stop.

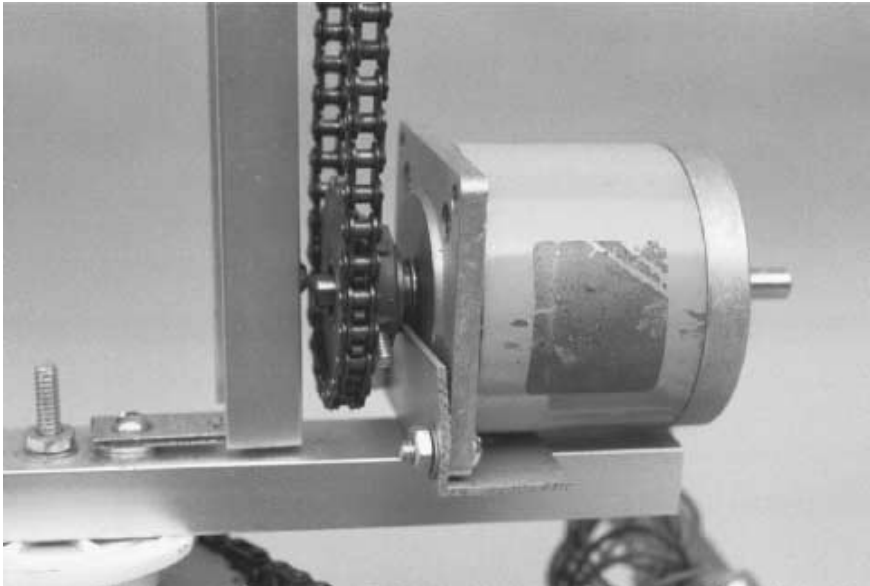
Drill mounting holes in the rail to match the bolts already in place on the elbow platform (you may need to remove the inner rail to get to some portions of the base). Unfasten the bolts on the side opposite the sprocket, and attach the rail. Retighten the bolts.

Mount the rail motor directly in the center of the elbow platform. Cut another 3 1/2-inch length of 1-inch-by-1-inch-by-1/16-inch aluminum angle stock and attach it to the platform using 8/32 by 1/2-inch bolts and nuts. Secure the motor using the mounting technique that is best suited for it. The stepper motor used in the prototype arm already had threaded mounting holes on the shaft end. These were used to secure the motor in place.

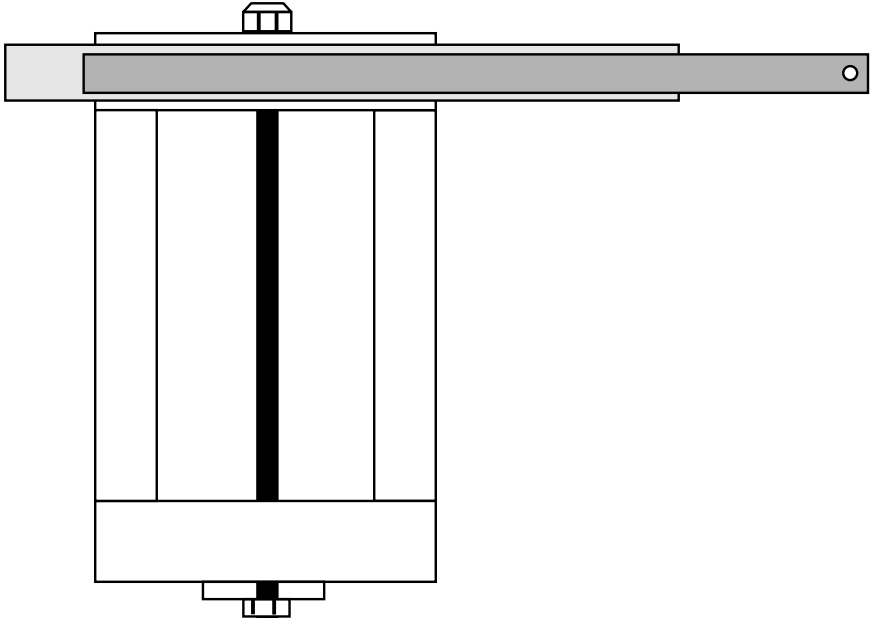
Attach two 1 1/2-inch-diameter gears to the motor shaft. Position the gears so the hubs face each other. The idea is to create a spool-like shaft for the forearm cable (see Fig. 26.10). Alternatively, you can use sprockets or fashion a real spool out of metal or wood.



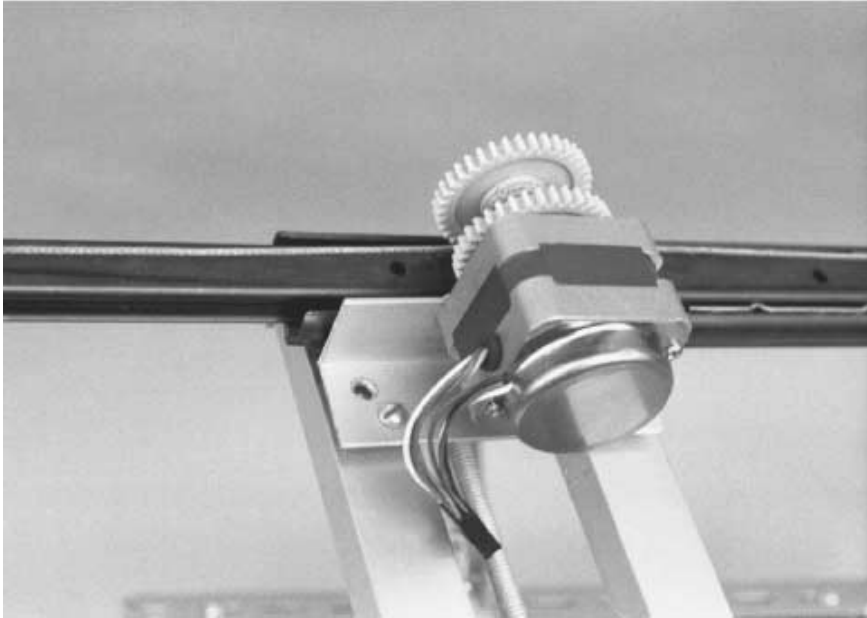
**FIGURE 26.7** *b.* Exploded view.



**FIGURE 26.8** Mounted elbow motor with chain sprocket and roller chain.



**FIGURE 26.9** The recommended mounting location for the drawer rail.



**FIGURE 26.10** The rail motor mounted in place.

The main design consideration is that the inside of the spool must be flush. Setscrews that bulge out will tangle with the cable.

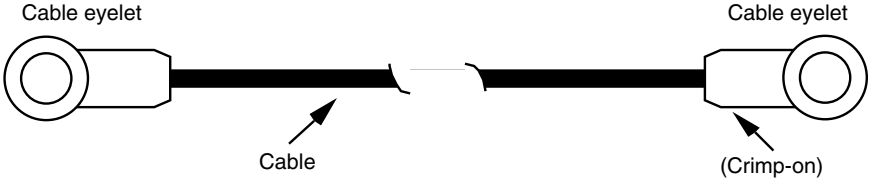
Cut a length of 1/16-inch-round steel aircraft cable to a length of approximately 18 inches. On both ends, clamp a 14-to-16-gauge wire lug using a pair of pliers or clamping tool (see Fig. 26.11). Secure one lug to the back end of the rail using 6/32 by 1/2-inch bolts and nuts (there may already be a hole for the hardware; if not, drill your own).

Loop the cable once around the spool shaft and pull it tight to the other end. Remove as much slack as possible and make a mounting mark using the wire lug as a guide. Drill the hole and secure the lug using 6/32 by 1/2-inch bolts and 6/32 nuts. The assembly should look similar to Fig. 26.12.

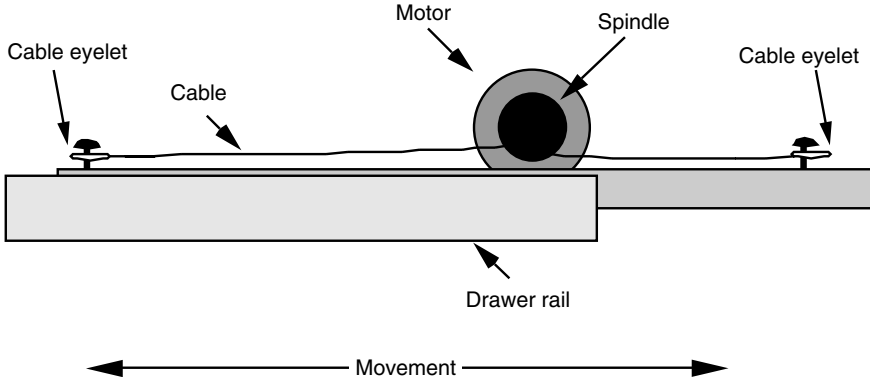
You may find that when you use metal or plastic gears or sprockets for the spool, the cable slips around and doesn't have much traction. One solution is to line the spool shaft with a couple of layers of masking tape. This approach has proved satisfactory for the prototype arm, even after several years of use. Alternatively, you can rough up the shaft using coarse sandpaper.

The finished polar coordinate arm is shown in Fig. 26.13. Note that the shoulder is able to rotate continuously in a 360° circle and will keep on rotating indefinitely like a wheel. In actual use, the wires to the motors will prevent the shoulder from rotating more than one complete turn.

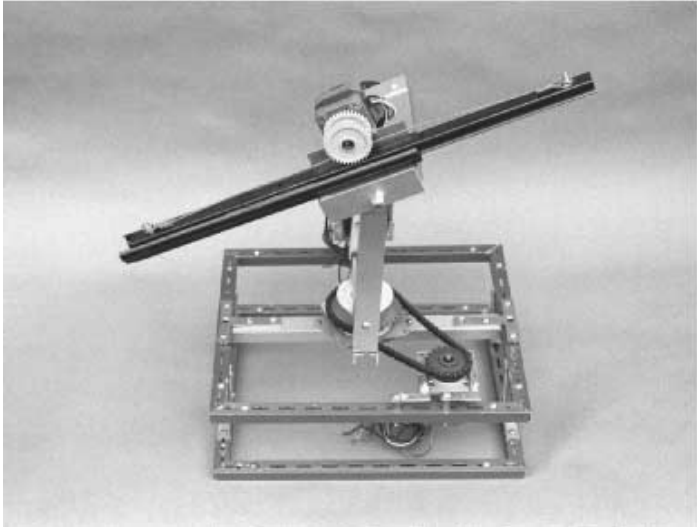
When the forearm is completely extended, its reach is not quite to the ground (but it is to the arm's own base). This reach is just about right as most gripper designs will add at least five or six inches to the length of the arm. The robot should be able to pick up small



**FIGURE 26.11** A length of aircraft cable terminated with crimp-on electrical lugs. The 14-to-16-gauge wire seems to work with 1/16-inch-diameter steel cable.



**FIGURE 26.12** Threading detail for the drawer cable assembly.



**FIGURE 26.13** The finished polar coordinate arm.

objects placed a half-foot or more from the base. You can increase the reach by making the base thinner or by using a longer drawer rail.

## Going Further

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There is room to improve this basic design for a polar coordinate arm. One improvement you can make quite easily is to add crosspieces to support the turntable used for shoulder rotation. As it is, there is a great deal of side-to-side slop, and additional braces would largely eliminate it.

Arm systems need a great deal of position control if the robot is to manipulate objects without direct intervention from you, its human master. See Chapter 25, “Build a Revolute Coordinate Arm,” for more complete details on adding position control to the joints of arms.

## From Here

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### *To learn more about...*

Using DC motors and shaft encoders  
Using stepper motors to drive robot parts  
Different robotic arm systems and assemblies  
Attaching hands to robotic arms  
Interfacing feedback sensors to computers

### *Read*

Chapter 18, “Working with DC Motors”  
Chapter 19, “Working with Stepper Motors”  
Chapter 24, “An Overview of Arm Systems”  
Chapter 27, “Experimenting with Gripper Designs”  
Chapter 29, “Interfacing with Computers and microcontrollers”