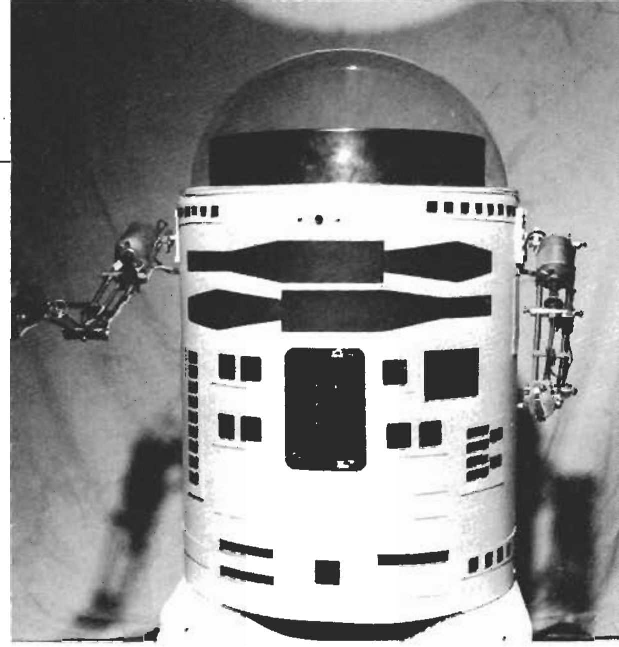
BUILD THIS ROBOT FOR UNDER $400

BUILD THIS

UNICORN-1 ROBOT



Ready for your own robot? You can construct one by following this multi-part series—and you won't need an engineering degree or special equipment, either.

JAMES A GUPTON, JR.

ROBOTS ARE BECOMING VERY HOT ITEMS. They have already made a name for themselves as movie and TV stars, chess players, artists, typists, advertising men, and assembly-line workers in Detroit. This past April, a three-day conference and an exposition on robotics was held in New York.

This series of articles detailing the construction of a robot called Unicorn-One (a name loosely derived from *Uni*versal *Con*trollable *R*obot) may not tell you how to build a device as elegant or articulate as *C3-P0*, but it will explain, step-by-step, how to design and assemble a robot that will be fully mobile, with manipulator arms to grasp, lift, and carry. Those features, in combination, will enable your robot to perform a wide variety of useful functions.

Unicorn-One is *truly* universal. The same robot body you will build can be operated from a control panel linked to it by cable, by remote radio control, or even by computer. It will even be possible to add an on-board computer to give the robot the ability to "think" for itself. As you will see, Unicorn-One's expansion capabilities are really limited only by what you want it to do.

The first parts of the series will deal with the construction of the mechanical portion of the robot—the object being to build a working mechanism for a reasonable amount of money.

You'll be shown how just a few common tools can be used to work steel and aluminum to almost machine-shop perfection. With a little ingenuity, an operational version of Unicorn-One can be built for about $200. Even if you purchase everything off-the-shelf, the cost should not exceed $400.

Easy-to-follow instructions will be provided to assist you in the assembly of the robot's manipulators (arms), end-effectors (hands), body, and mobility base, and will detail all wiring necessary to power its moving parts. For convenience, this wiring will be brought out to a terminal strip, where it can be connected to whatever type of control equipment you desire to use.

Later installments will describe how the robot can be controlled in any of several different ways—from a cable-connected console or by radio link, providing for both manual and computer-controlled operation.

Provision is also made for the installation of an on-board computer which can be programmed in advance, reprogrammed in mid-sequence, or even left to operate on its own.

The final portion will discuss ways of providing Unicorn-One with senses such as touch and sight, giving it a way to understand and communicate with people, and, in addition, giving it the ability to react to its environment without human intervention.

Basic mechanical components

Since we are building a robot from scratch, it might be a good idea to become familiar with some of the major components which affect its operation.

There are two electro-mechanical parts which are used to impart motion to the robot—motors and solenoids.

Motors are used for continuous motion (in the mobility base, for example, to get from one place to another, or in the arms, for lifting). Solenoids are usually used for a "one-shot" effort—say, opening or closing a grasping member.

Several different types of motors are used in Unicorn-One. Typically, they are low-voltage, high-speed, DC motors which are slowed down (they operate at several thousand RPM) to do what we want them to. That slowing-down is accomplished by gears, which gives us two benefits.

First, the rate of speed is reduced to a "real-world" level and, second, each time the speed is reduced by half, the torque (effective power) is doubled. That allows us to use inexpensive motors to give our robot a reasonable amount of strength. The same principle is used in automobile transmissions. (You can spin your wheels in low gear, but you can't start to build up any real speed until you get into second or higher.)

To put it in mechanical terms, if a motor spins at 6000 RPM, it won't do much for our robot arm unless it is geared down to make the action slower and more powerful. If we attach a 12-tooth gear to the motor, and mesh that with a 24-tooth gear, we'll achieve a speed reduction of 1:2 (12:24) and, at the same time, double the effective power of the motor. Every time the twelve-tooth gear turns once, the other will make only half a revolution, while transmitting the full power of the entire original revolution—which, if you add it up, doubles the original power of the motor.

GLOSSARY

Anti-backlash gear—Gear used to reduce or eliminate backlash. See BACKLASH, GEAR.
Angular motion—Rotary motion about an axis, as in the case of wheels or gears.
Backlash—Unwanted "rebound" movement in gear systems resulting from inertia.
Center punch—Pointed tool used to indent the surface of hard materials for marking purposes or to form a starting point for drilling.
Computer control—Direction by means of instructions programmed into a computer.
End-effector—Unicorn-One's "hand."
Gear—Toothed wheel or cylinder that meshes with another to transmit motion or to change speed or direction.
Gear ratio—The relation between the number of teeth on one gear and another. The higher the ratio, the greater the reduction in speed and the greater the increase in torque.
Manipulator—Unicorn-One's "arm."
Mobility base—The part of the robot that gives it locomotion.
Radio control—Direction by means of instructions transmitted by radio to a receiver located at the object being controlled.
Robot—Machine that works automatically or by remote-control. Generally assumed to be manlike in shape and function. NASA's space and planetary probes, however, are robots, and they don't look the least like us.
Robotics—The science of robots.
RPM—Revolutions per Minute
Scribe—Pointed tool used to mark hard surfaces to indicate areas to be cut, sawed, or drilled.
Sensor—Device which responds to a stimulus. A photo-electric cell would be an example of a light sensor.
Shaft—Rotating rod or bar which transmits mechanical power.
Solenoid—Electromagnet with a ferrous-metal rod through its core. An induced magnetic field causes the rod to move in or out of the core.
Sprocket gear—Large-toothed gear whose teeth ride in the links of a chain and impart motion to it.
Switch-control—Operation of an electrical or electronic device through the opening or closing of a circuit.
T—Abbrev. for "teeth."
Tap—Screw-like cutting tool designed to cut threads into drilled holes.
Tap drill—Drill bit whose diameter is best suited for use with a particular tap.
Thread—Spiral or helical ridge of a screw, bolt, nut, etc.
TPI—Abbrev. for "threads-per-inch."
Torque—Force that produces a twisting or rotating motion.
Unicorn—*Uni*versal *Co*ntrollable *R*obot.

Using various gearing systems we can easily reduce the speed of a 10,000 RPM motor to an effective 167 RPM, allowing us to use that motor to give real-time motion to the robot's arms.

If we use what is known as a worm gear, we can not only change the speed of the motor—and increase its torque—but also change the direction of the motion. Such an effect can be used effectively in the robot's mobility base.

Various gear assemblies can also change a motor's output from angular (around the axis of the shaft) to linear—that is, from rotary to straight-line, as would be needed in order to push a "hand" forward.

Gears can also be used simply to change movement from one direction to movement in another (say, through an angle of 45°).

The second type of motor used in Unicorn-One is the *stepper motor*. That type of motor responds by turning just a little bit for each electrical pulse it receives. Thus it is possible to move a stepper motor just a fraction of a degree at a time, as might be required in steering the robot. If large amounts of motion are required, multiple pulses are applied.

In addition to the motors, we also use *solenoids* to control the robot's motion. A solenoid is an electromagnet which has a ferrous-metal core. When the magnet is energized, the core—usually a free-sliding metal rod—is either pulled into, or pushed out of, the magnet's coils. Unicorn-One uses solenoids to actuate its grasping members (hands/fingers). If power is applied, the solenoid is actuated and pulls the core inwards. That movement causes the "fingers" to close and to grasp the object in question; the grasp will be maintained until power to the solenoid is cut.

Some solenoids also incorporate gears,

UNICORN-ONE nearing completion. Humans at work give idea of robot's size.

and rotate the gears, and their attachments, through a specified angle, when they are actuated. (They may turn a wheel 45° at a single, momentary command, for instance.)

Finally, we have to consider *limit switches*. Those are absolutely necessary to the well-being of the robot. If we actuate a motor and do not, later, tell it to shut off, we are liable to do damage to the mechanical parts of the robot or even to burn out the motor itself. The limit switch is a device which senses when a mechanical part has reached the predetermined limit of its travel and opens (or closes) the appropriate electrical cricuit to stop the device which is causing the part to move. Limit switches are an inexpensive way to give a measure of control to your robot without your having to pay attention to its every movement.

In addition to the above, we will also use cables and pulleys, anti-backlash gears, bearings, and other mechanical devices to give motion to Unicorn-One.

As we encounter those various components in the construction of Unicorn-One, we'll go into a greater description of their function and operation, and explain why we are using them.

Manipulator construction

The construction of a robot, judging from the available literature, is an expensive proposition, involving skills, materials, and tools not normally encountered in the type of project presented in **Radio-Electronics.** We'll dare to be different here, however, and show you how you can build Unicorn-One using tools you probably have on your work bench and materials that are easy to come by. Even if you have never worked with metals before, we'll provide you with the knowhow to construct a working robot.

The drawings in Fig. 1 show the dimensions for a robot of ideal size. You may, however, decrease or increase those dimensions to suit your budget or needs. Bear in mind that, for radio or remote control, where the power source must be self-contained, the robot's overall weight becomes a very important factor and you may want to deviate from the dimensions given.

The first portion of Unicorn-One that we'll construct will be the manipulators (arms). They will be fabricated from steel rod and aluminum plate, and dimensions and instructions for the metalworking will follow. We'll describe the construction of one manipulator. If you want a two-armed robot, do everything twice. Before you proceed, though, read and heed the following precautions about metalworking:

- Always wear safety goggles or glasses when sawing, drilling, tap-

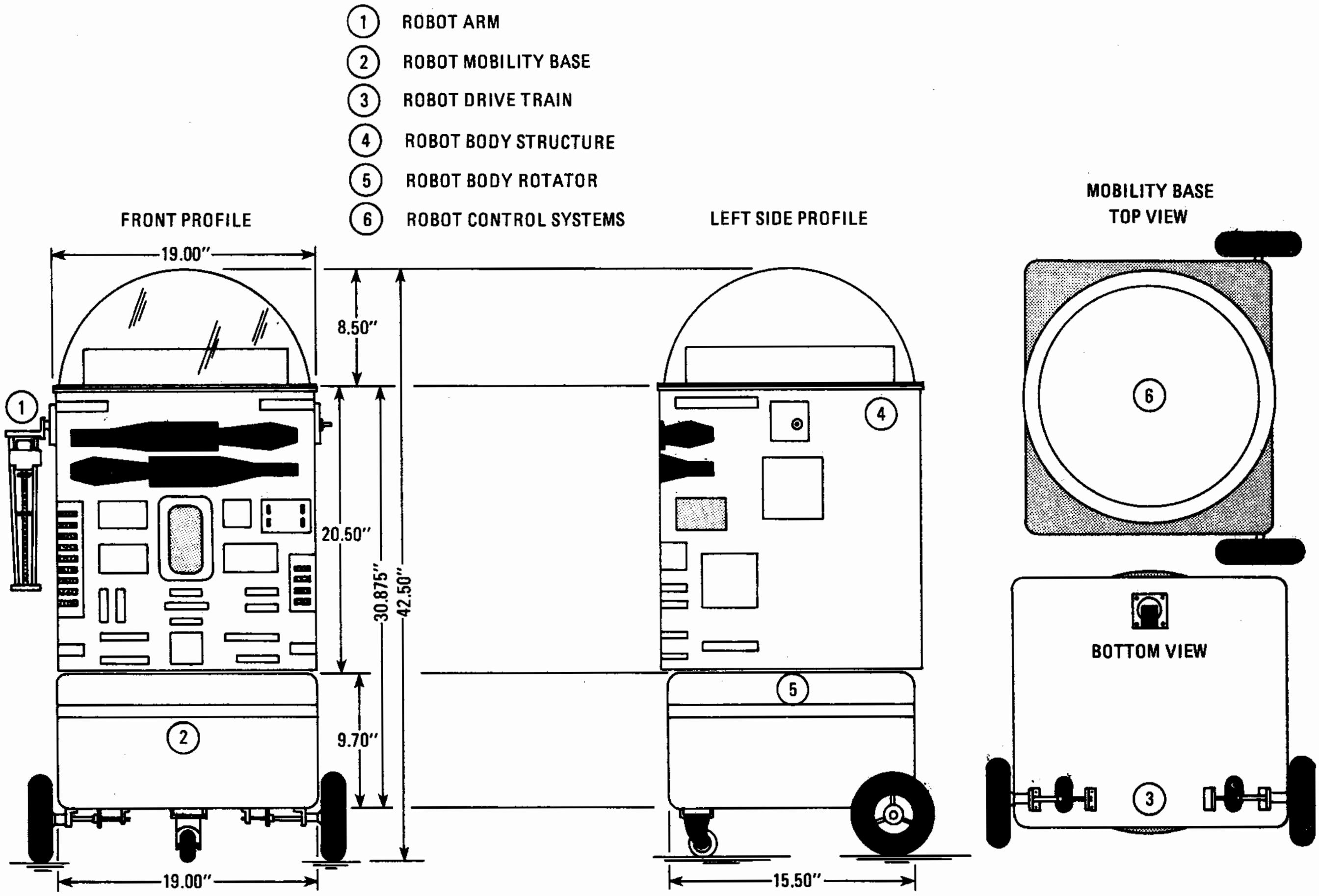


Fig. 1—DIMENSIONS of Unicorn-One as described in text. Size is not critical, though, and scale or dimensions may be altered to suit the requirements of the builder.

ping or filing metal (or wood or plastic)

- Never wear ties or loose clothing when operating power tools
- Hold tools properly and make sure pieces being worked on cannot move around

The instructions which follow are intended to be used in conjunction with the diagrams which accompany them. Do not try to rely only on one or the other. If you have a question, the diagrams can probably supply the answer if you study them.

Basically, there are only two different diameter steel rods used to make all the manipulator sections. The cross members are cut from 0.375-in. (3/8-in.) steel rod and the side rods from 0.2497-in. (1/4-in.) material. The threaded steel rod is 1/4 inch in diameter with 20 threads-per-inch. The shoulder and elbow hinges, and the two contractor-bar pivots, are cut from 0.250-in. (1/4-in.) aluminum plate.

The aluminum parts should be made first since they require more work than the rod sections. To keep costs low, use scrap material wherever you can.

The first step is to mark the dimensions of the aluminum part. Do that with a scribe, pointed nail, or even a knife. Don't use pencil, since it rubs off easily. When you cut the part, cut along the *outside* of the lines. You can always file off excess, but it's impossible to put back a little bit too much you removed while cutting. Use a vise to hold the piece steady and use a hacksaw blade with 24–32 teeth-per-inch to give a smooth cut.

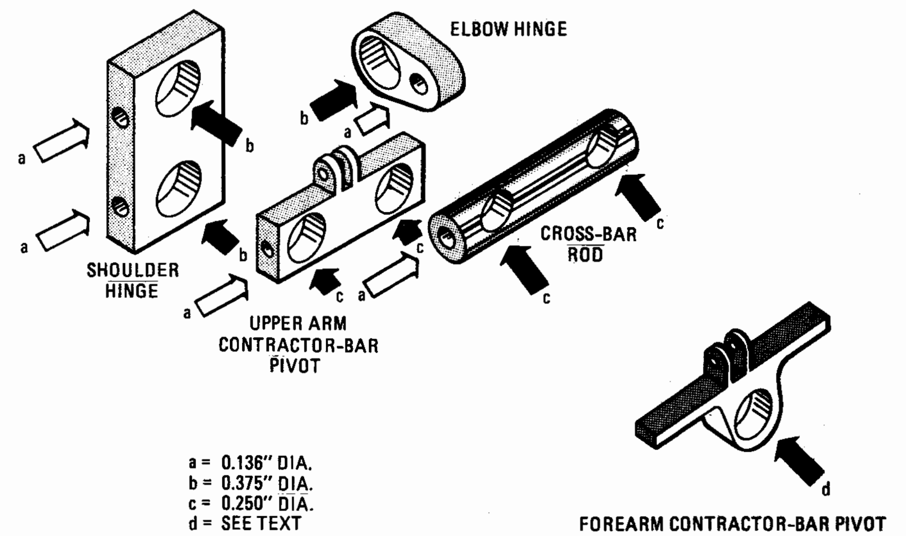


Fig. 2—DETAILS of the aluminum parts which must be fabricated. Steel cross-bar rod is also shown as an example. Note that there are several different versions of this part.

The shoulder-hinge sections are two rectangles, 1 × 1.4 inches, drilled to accept two 3/8-inch rod sections (Figs. 2 and 5). There are two ways by which the steel rods can be secured to those hinge sections: a 1/16-inch hole can be drillled through each for use with roll or dowel pins, or a No. 44 bit (.086 inches) can be used to make a hole which can be tapped for a 4-40 machine screw. Figure 3 shows some of the taps and tap drills that can be used in the construction of the robot.

For the elbow hinge (Fig. 2), outline the part on the aluminum plate and, using a punch, mark the places where holes will be drilled. Saw out a rough rectangle and drill the .375- and then the .136-inch holes. With the holes drilled, the part can be cut and filed down to the proper size.

The two contractor-bar pivot parts (Fig. 2) require a little more work. Again, cut the parts roughly to size (see Figs. 2 and 5). As in the shoulder-hinge pieces, either a dowel pin, or a 4-40 machine

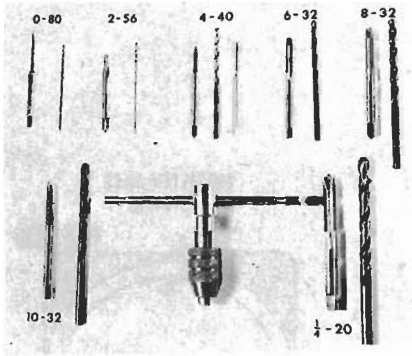


Fig. 3—TAPS AND TAP DRILLS. First number indicates size; second, threads-per-inch.

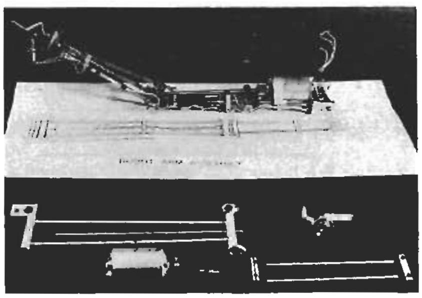


Fig. 4—MANIPULATOR ASSEMBLY. Finished unit and separate pieces are facing opposite ways.

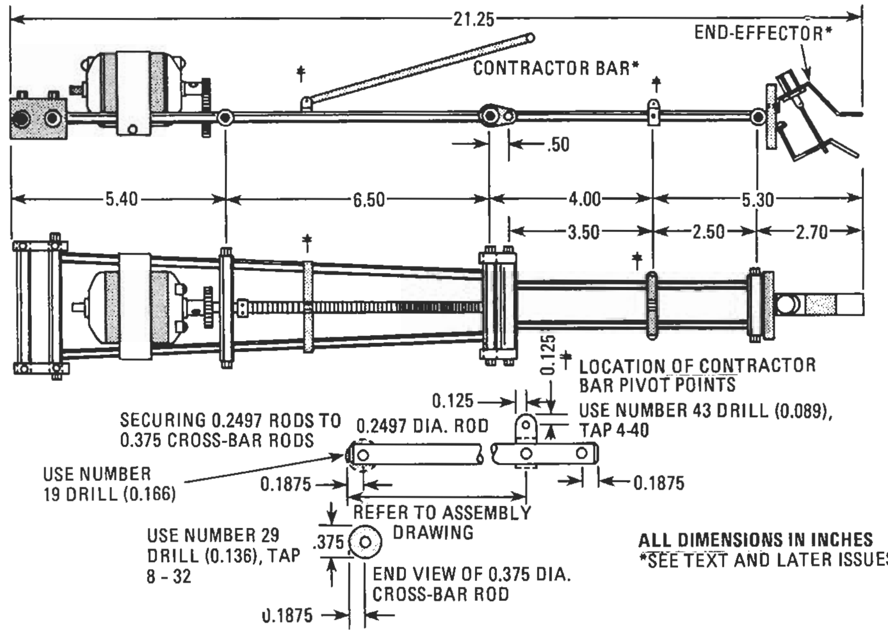


Fig. 6—SIDE AND TOP views of the assembled manipulator. End-effector and contractor-bar will be covered in the next installment.

screw, may be used to provide the pivot support. The upper-arm pivot part has a tapped 1/4-20 hole for the 1/4-20 threaded rod used to provide elbow action. That hole may be made either with a #7 bit (.207-in.) and tapped to 1/4-20 or drilled out slightly larger—.413 in. minimum—to accept a threaded insert, which will give a smoother action. The latter approach is preferred, but the former will give satisfactory results, provided the work is done with care. Both pivot parts should be carefully cut and filed to shape.

To prepare the six steel cross-bar rod sections, cut each length slightly longer than called for. There will be two 3.25-inch sections, two 2.6-inch sections, one

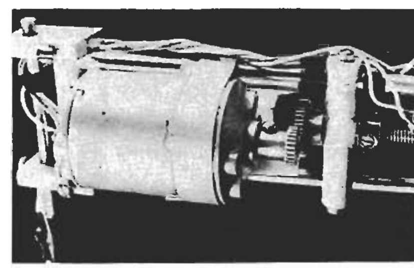


Fig. 7—MOTOR AND GEAR arrangement used to drive threaded rod, as described in text.

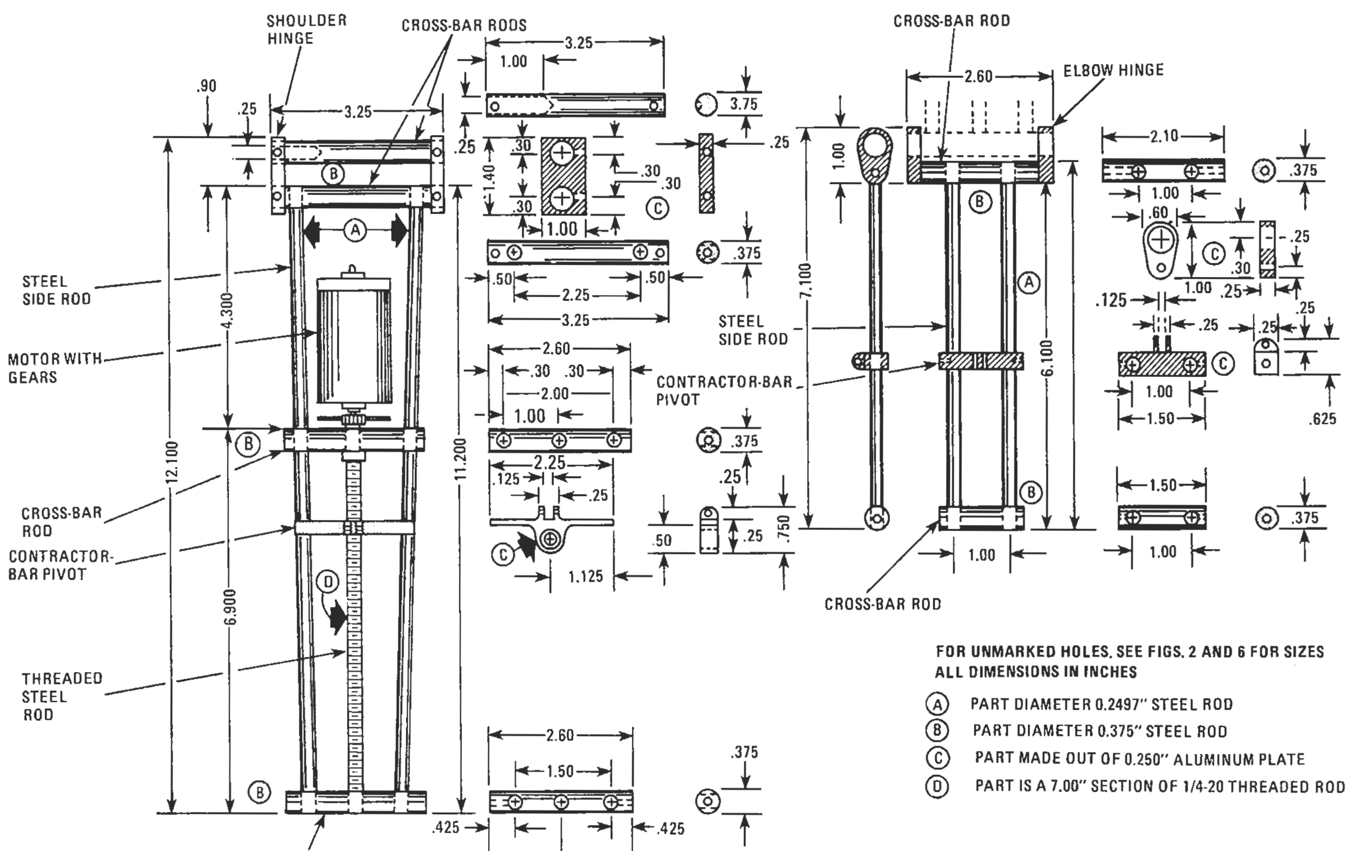


Fig. 5—FABRICATION AND ASSEMBLY details of the manipulator. It would be a good idea to make a copy of this and keep it near your workbench for reference.

PARTS LIST

Item	Size	Quantity	Supplier's part no.	Supplier
Steel rod	0.2497 in. diam.	72 in.	SR 500	(A)
Steel rod	0.2497 in. diam.	72 in.	SL-14	(B)
Steel rod	0.375 in. diam.	36 in.	SR 375	(A)
Steel rod	0.3497 in. diam.	36 in.	SI-33	(B)
Sheet aluminum	0.0625 in. thick	6 x 12 in.*	SA 625	(A)
Sheet aluminum	0.250 in. thick	1 x 18 in.	SA 250-18	(A)
Sheet aluminum	0.250 in. thick	1.5 x 6 in.*	SA 250-9	(A)
Threaded insert	OD 0.413 in. TPI ¼-20	2	TI 1420	(A)
Threaded rod	¼-20	14 in.	TR 25020	(A)
Threaded rod	¼-20	14 in.	TI-7	(B)
Reduction gears	20 T, 0.458 diam. ¼-in. bore, 48-pitch	2	G 20 T-48	(A)
Reduction gears	48 T, 1-in. diam. ¼-in. bore 48-pitch	2	G 48T-48	(A)
Shaft collar	OD 0.50 in. ID 0.2497 in.	4	C 525	(A)
Shaft collar	OD 0.50 in. ID 0.2497 in.	4	C5-7	(B)

Item	Size	Quantity	Supplier's part no.	Supplier
Dowel pins	OD 0.0625 in. 5/8-in. long	6	D16-625	(A)
or				
4-40 screws	4-40 x 5/8 in.	6	Z9-4-40-A10	(B)
8-32 screws	8-32 x ½ in. socket-head screws	44	Z9-8-32-A8	(B)
Elbow motor	12 VDC, ¼-in. diam. shaft	2	P-42,670	(C)

SUPPLIERS:

(A) **The Robot Mart**
Room 1113
19 W. 34th St.
New York, NY 10001
(Catalog $3.00)

(B) **Winfred M. Berg, Inc.**
499 Ocean Avenue
Rockaway, NY 11518

(C) **Edmund Scientific Co.**
101 East Gloucester Pike
Barrington, NJ 08007

The above suppliers have catalogs available upon request.

NOTES: Items grouped together are interchangeable. Items marked with "*" include quantities for end-effectors. Suppliers shown are not necessarily the only source for items indicated.

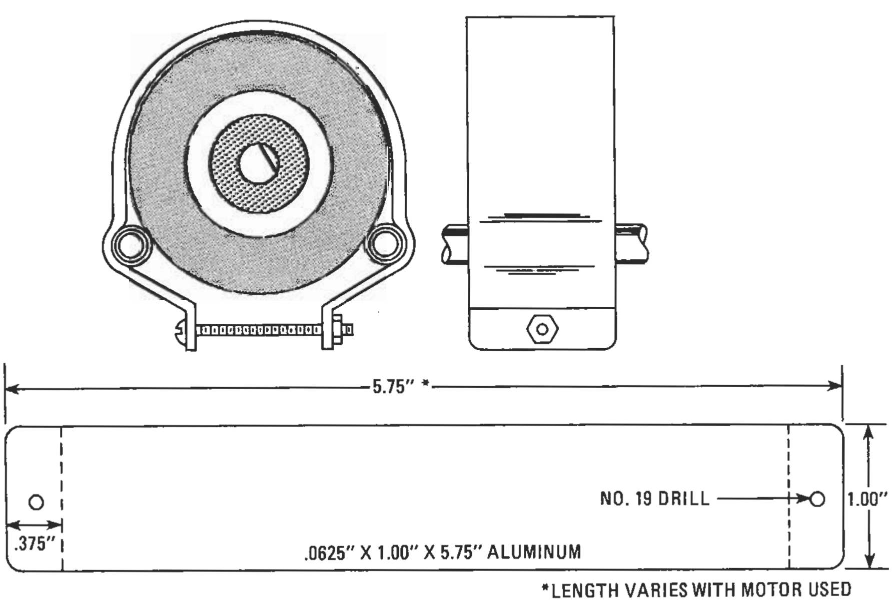


Fig. 8—ATTACHMENT OF DC motor to side rods. Clamp dimensions will vary according to the particular motor used.

2.1-inch section and one 1.5-inch one. Lock each piece into the chuck of a variable-speed electric drill and remove the saw marks by running the drill slowly and filing the rotating rod. When the saw marks have disappeared, angle the file approximately 45° to the rotating stock and lightly bevel the end of the section. Reverse the rod and repeat the procedure on the other end. Next, with the rod still in the chuck, polish its surface with "A" grade silicon-carbide paper. That will give the rod a high-luster finish and remove any remaining surface scratches. The procedure is best carried out by two people.

Carefully drill the rod sections to receive the 0.2497 in. side rods. Each hole drilled must be perpendicular to the rod and parallel to the other hole. If they are available to you, a drill press and "V"-block should be used to make sure of this. To allow the arm to taper, enlarge the holes slightly by "wobbling" a hand-held drill in them.

Figure 4 is a photograph of a fully assembled manipulator (with end-effector) and assembly details are given in Fig. 5. Also refer to Fig. 6. Those should help you to picture what has to be done, and where.

Drill into both ends of five of the six rod sections using a No. 29-bit (.136 in.). Use a punch to mark the center of the rod's diameter and to avoid slippage of the bit. Drill deeply enough to penetrate the .250-inch side-rod holes made previously. One of the 3.25-inch sections—the one which will be used at the top of the arm—gets a .250-inch hole, 1 inch deep, in one end. That will later be used to anchor the arm to the body.

Assemble the two 3.25-inch cross-bar rods and the rectangular shoulder-hinge plate. Use a center punch to mark the rods *through* the .136-inch holes in the plate. Take the assembly apart and use a No. 19 bit (.166 in.) to drill into the rods at the four places marked. Then tap those holes for an 8-32 thread. Also use an 8-32 tap on the .136 in. holes which were drilled into both ends of five of the rods.

Check your work against the diagrams
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to make sure that you have not omitted a step. It will be very frustrating if you are halfway through assembling the arm and discover that you have to take it all apart again to drill one small hole that you omitted earlier.

Arm movement

The upper-arm assembly includes a section of $\frac{1}{4}$-20 threaded rod which, when rotated by the elbow motor, allows the robot to flex its arm. The threaded rod, which passes through the threaded hole in the pivot slide bar, will move that bar one inch for every 20 revolutions it makes. Using the dimensions given, this will produce a maximum travel of 5.5 inches. A motor turning at 6600 revolutions per minute would be required to flex the elbow through 90° in four seconds.

The most readily available motor, however, turns at 10,000 RPM and would make that action too fast. If we add a one-inch diameter, 48-tooth gear to the threaded rod, and a $\frac{1}{2}$-inch, 20-tooth gear to the motor, we reduce the effective speed of the motor by 50% and can achieve full elbow action in a bit under ten seconds. Figure 7 illustrates that arrangement. Note that the threaded rod has a collar secured to it by a set screw. The collar prevents the rod from being pulled upward by the motor.

Figure 8 shows a clamp joining the motor and the side rods of the upper arm. That clamp is made from a piece of $\frac{1}{16}$ x 1-in. sheet aluminum flared to accept an 8-32 bolt which applies tension to hold the motor in place.

While the preceding may sound somewhat complex at first reading, it *can* be done and will yield a perfectly workable robot arm. You are encouraged to use surplus sheet metal, rods, and gears to keep costs down. For convenience sake, however, a list of components and their sources is shown in the parts list.

The next part of this series will describe the assembly of the manipulators and will cover the construction of the robot's end-effectors (hands). In addition, we will go into the electrical wiring of the manipulators.

Should you have a question about any part of this series, the author may be reached in care of **Radio-Electronics.** Please enclose a self-addressed, stamped envelope with your inquiry to insure a prompt reply. **R-E**