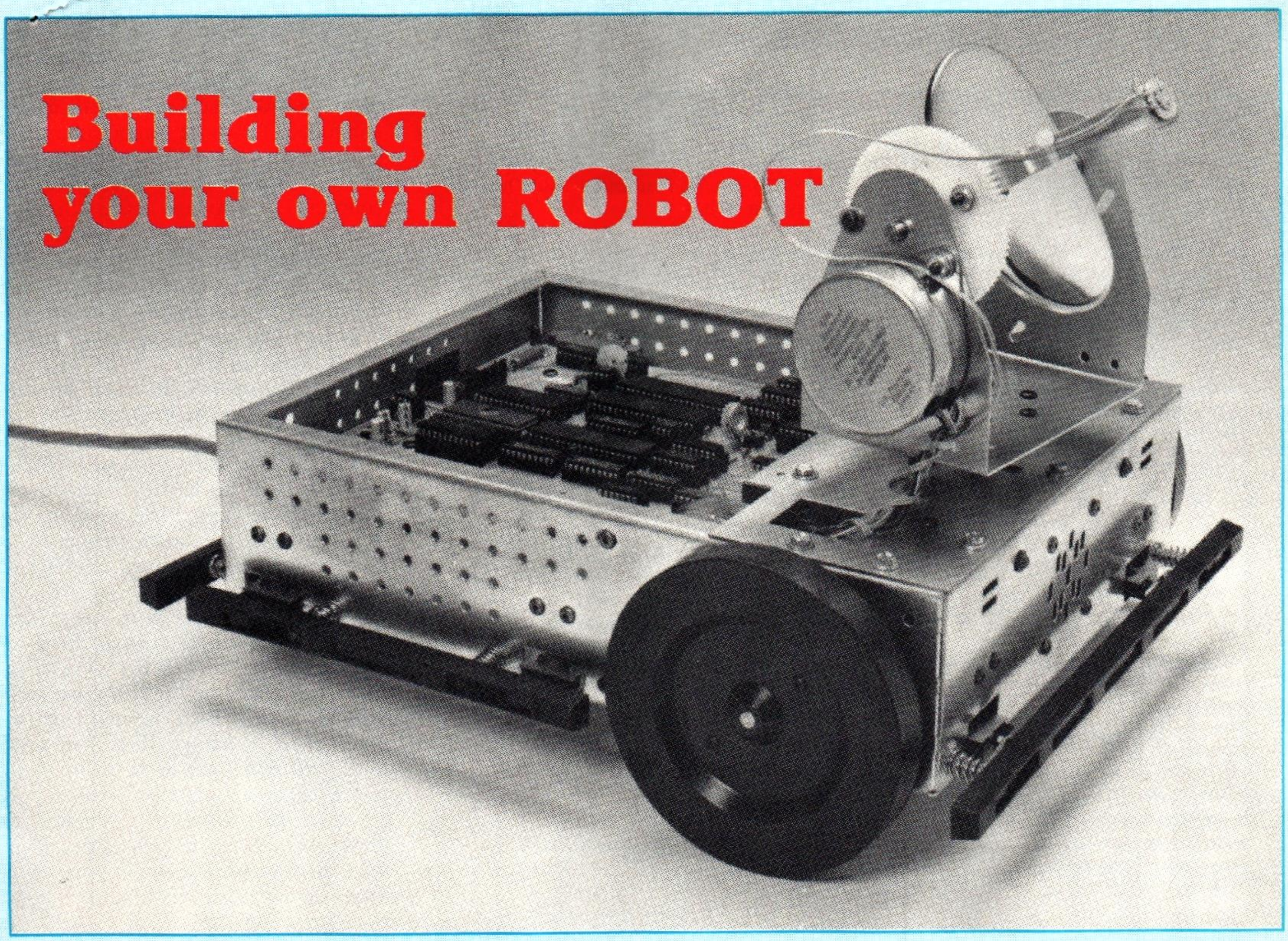
Building your own ROBOT



If you can't find the robot you are looking for, why not build it yourself? Here are some pointers to help get you started.

MARK J. ROBILLARD

MUCH LIKE ARTISTS WHO TOIL WITH MESSY pastes to create their masterpieces, there are artisans who use the tools of technology to fashion their creations. In electronics, there is almost always a new art form to present a challenge to those creative minds. Three decades ago, two-way voice and code communications presented the challenge. Ten years ago it was the microcomputer that captured their fancy. Today, it's the robot.

Although experimenters were building robot-like machines decades ago, none could approach the sophistication of today's units. Several companies have begun offering both complete kits of parts for everything from robotic arms to complete computer-controlled robots. Because of the demand by hobbyists, many traditional electronics-parts suppliers are beginning to carry more robot-oriented supplies.

This article is for those of you who would like to try building your own robot. Here, we will attempt to tell you about the various components you might need, and, if possible, where they can be obtained.

Getting started

Whenever you are starting a new venture, it is useful to have some idea about what you are getting into. And, although you must have already had some exposure to the field for personal robots to interest you, there's always room for more knowledge. Thus, the best way to start is to get hold of as many good robotics books as you can.

There are a wealth of books available now. They range from the theoretical to the practical. Some of the better ones are listed in Table 1.

One problem with such books is that the information they present can become out-of-date quickly. For more up-to-date information, you may want to consult one of the magazines that cover the field. At the present, there is only one periodical dedicated to the robot craftsman. *The Robot Experimenter* (174 Concord St., Suite 31, PO Box 458, Peterborough, NH 03458) was created to fill the void after *Robotics Age* (174 Concord St., Peterborough, NH 03458) began covering only industrial robotics. For those of you with more than a passing knowledge of the field there are two professional journals that should be of interest. Those are the *International Journal of Robotic Research* (28 Carleton St., Cambridge, MA 02142) and the *Journal of Robotics Systems* (605 Third Ave., New York, NY 10157). Both report on the latest in robotics research throughout the world.

All about parts

If you are like most of us, about halfway through reading about robot construction, you'll develop an insatiable desire to begin tinkering. To keep yourself sane, you might want to have some basic robotic parts on hand for that moment.

When you think about robots, the first thing that should come to mind is motors. (You could also build a robot using pneumatics, but such a device would be out of place in the home.) Things are a lot easier now than they used to be. Just a few years ago, the overwhelming majority of the available hobby motors were simple three-volt types. On their own, those had negligible "pulling" power. To do any

TABLE 1—ROBOT BOOKS

How To Build A Computer-Controlled Robot
Tod Loofbourrow
Hayden Publishing
Rochelle Park, NJ 07662
$7.95

Build Your Own Self-Programming Robot
David Heiserman
Tab Books
Blue Ridge Summit, PA 17214
$10.25

Robotics Age: In The Beginning
Edited by Carl Helmers
Hayden Publishing
Rochelle Park, NJ 07662
$19.95

The Complete Handbook of Robotics
Edward Safford
Tab Books
Blue Ridge Summit, PA 17214
$11.50

Microprocessor-Based Robotics
Mark J. Robillard
Howard W. Sams Inc.
Indianapolis, IN 46268
$16.95

Advanced Robot Systems
Mark J. Robillard
Howard W. Sams Inc.
Indianapolis, IN 46268
$19.95

Basic Robotic Concepts
John Holland
Howard W. Sams Inc.
Indianapolis, IN 46268
$19.95

How To Design And Build Your Own Custom Robot
David Heiserman
Tab Books
Blue Ridge Summit, PA 17214
$13.50

Handbook Of Advanced Robotics
Edward Safford
Tab Books
Blue Ridge Summit, PA 17124
$16.50

How to Build Your Own Robot Pet
Frank Dacosta
Tab Books
Blue Ridge Summit, PA 17124
$8.95

Design And Application Of Small Standardized Components
Data Book 757, Volume 2
Stock Drive Products
Educational Products
PO Box 606
Mineola, NY 11501
$7.95 (paperback)
$12.95 (hardcover)

Apple II/IIe Robotic Arm Projects
John Blakenship
Prentice-Hall Inc.
Englewood Cliffs, NJ 07632
$16.95

useful work, a complex gear-train assembly was needed. The cost was nearly a hundred times higher than that of the motor itself.

Fortunately, that has changed; it is now possible to purchase hobbyist motors that can actually do something. For those interested in experimenting with arms, the *Robotix 2000* building set from Milton Bradley (Springfield, MA 01101) is recommended. That kit contains four motors with integral gear trains, and a host of other structural pieces. Using the kit, it is possible to build a four-jointed arm, complete with gripper (supplied), in approximately five minutes. The motors are connected to manual control boxes via plug-in cables. It is also a simple matter to control those motors using a computer. To get some idea of how it can be done, see "Computer-Controlled Robot Arm," in the May 1985 issue of **Radio-Electronics**.

Another source for motors is H&R Corporation (401 E. Erie Ave., Philadelphia PA 19134). They have an impressive selection of some of the most powerful motors available to the hobbyist. Also impressive is the value you get for your money.

For some applications, you may find that stepper motors are more useful than DC motors. Steppers provide you with a greater degree of control. There are two basic types of steppers that are appropriate for hobby experimentation—the four-phase unipolar stepper and the bipolar stepper; the former is more easily obtained.

Stepper motors carry supply-voltage and mechanical-power ratings. The power rating has to do with the amount of work the motor is capable of doing. A motor with a rating of 1-ounce-inch is capable of pulling a 1-ounce weight, located 1-inch away, about its shaft pivot. That is shown in Fig. 1.

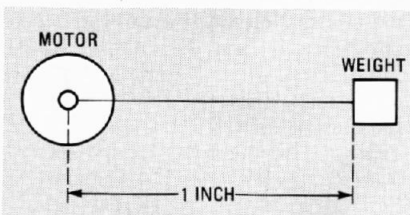


FIG. 1—THE AMOUNT OF WORK (torque) performed by a motor is equal to the weight to be lifted multiplied by the distance between that weight and the motor shaft.

The four-phase unipolar stepper motor is easy to control. Beside being able to interface them to microprocessor circuitry (through appropriate driver circuits), there are several sources of dedicated IC controllers for those motors. Basically, there are four separate windings and one or two common leads. The common is connected to a voltage source. To effect motion, one must supply a path for current to flow in each of the four windings by grounding their leads. The order in which the windings are energized determines the direction and the speed in which the motor turns.

Figure 2-*a* shows the basic hook-up scheme for a four-phase stepper. The transistors Q1–Q4 are the output stages of the driver circuitry. When a voltage is applied to the base of a transistor, it conducts, energizing the appropriate winding. Figure 2-*b* shows the timing sequence for those drivers for movement in either direction.

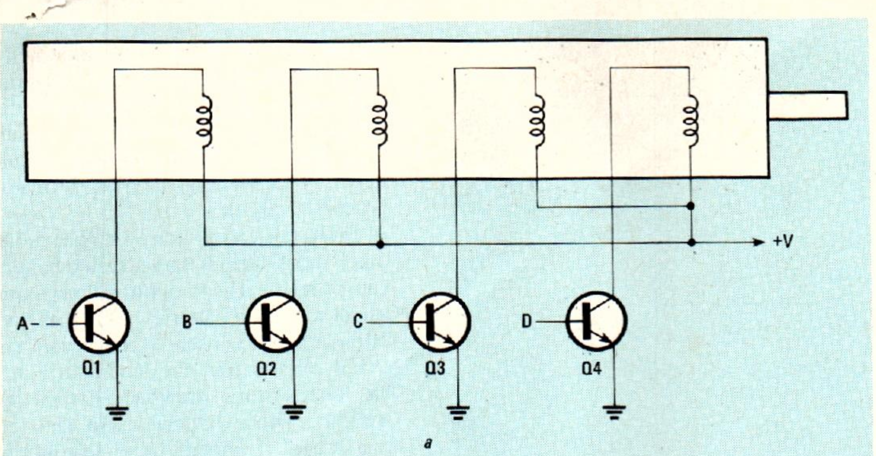
The bipolar stepper is connected in a different fashion. Its basic hook-up scheme is shown in Fig. 3-*a*. As you can see in that figure, there are only two windings. One side of each is connected to the power supply common. The other winding connections are used to direct the motor. Note that a bipolar power supply, ±5-volts in this case, is required for movement in both directions. Once again, the transistors are the output stage of the driver circuitry, and the timing sequence is shown in Fig. 3-*b*.

When would you use a bipolar motor over a unipolar type? For hobby robotics that decision really rests on the question of availability and price. If you have found a nice little stepper that has the torque required by your project, and it will run from the available supply voltages, then buy it. If you have questions about the hook-up required, most of the hobby suppliers will often send appropriate information along with the motor. Otherwise, many of the books listed in Table 1 provide information on how to hook up various motors.

Now that you've got the motors, you're going to need to mount them on something. Although it might sound archaic, one of the best building materials for robotics is wood. Wood is cheap, easily handled, and can be worked with using inexpensive tools. If you want your robot structure to look professional, simply paint it or finish it with plastic laminate.

Of course, wood comes in many grades, and some of those are not appropriate for this application. Regular lumber-yard-grade plywood is out. The voids in the middle of such woods make for a shabby appearance and drilling produces many splinters. For best results, stick with marine grade and special laminates.

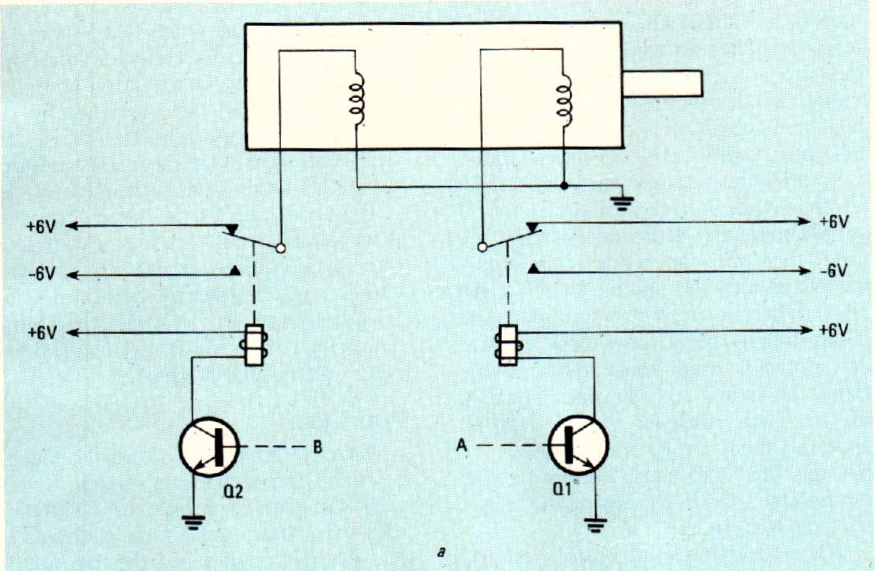
Other items you will need include fasteners, support rods, and various mechan-



	TRANSISTOR			
STEP	Q1	Q2	Q3	Q4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	ON
3	OFF	ON	OFF	ON
4	OFF	ON	ON	OFF
5	ON	OFF	ON	OFF

b

FIG. 2—HOOKING UP a four-phase stepper motor. The table in *b* shows the order in which the transistors must be turned on to advance the motor in the clockwise direction.



	TRANSISTOR	
STEP	Q2	Q1
1	OFF	OFF
2	ON	OFF
3	ON	ON
4	OFF	ON
5	OFF	OFF

b

FIG. 3—A BIPOLAR STEPPER is wired up in this manner. To advance the motor in the counterclockwise direction, revers? the turn-on sequence shown in *b*.

ical assemblies. The first place to look for those is a well-stocked hardware store. In fact any time you need wheels for robot carts, get the lawnmower type available in most stores. You can always get a replacement and they come in many sizes. The one standard feature of those wheels is that they all mount on half-inch diameter shafts.

To give you an idea of what can be accomplished with wood, take a look at Fig. 4. That "hand" has been built from wooden dowels and two pieces of thin aluminum. The motor that activates the gripping action is mounted in the middle palm region. The dowels are made of basswood and are available in almost all hobby shops. The aluminum was purchased in the same shop. If you prefer to work in plastics, your local hobby shop is also a good source for styrene; that's the

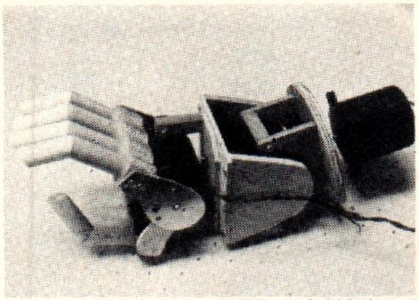


FIG. 4—THIS ROBOT "HAND" was build almost entirely from wood.

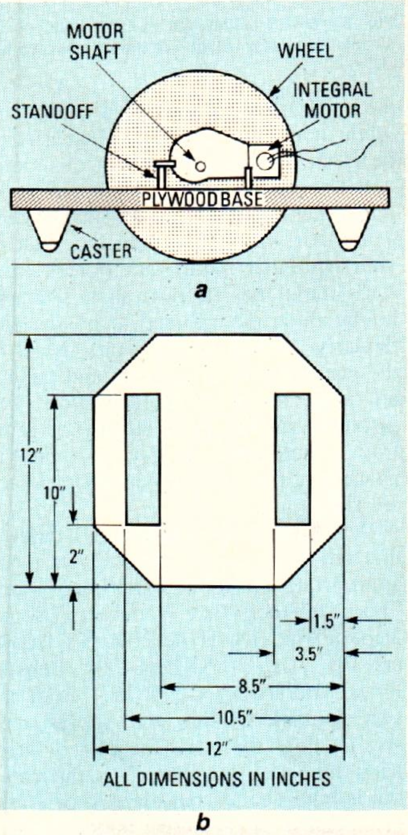


FIG. 5—A SIMPLE MOBILE BASE. A side view is shown in *a*; the top view in *b*.

material that's used to make airplane models.

Once you've got the motors and structural pieces on hand you can start tinkering. A two wheeled cart using two furniture casters for balance is a simple first project. The layout for a cart of that type is shown in Fig. 5.

Once you've built the cart itself, it's time to devise a control system. Your first effort should be to build a system to control the cart manually using a joystick. Hook up the switches in the joystick so that they control the motors to move the cart in the appropriate direction.

Once you get the basic operation of the cart down, its time to add more functions. To do that, you'll need more parts. Gears

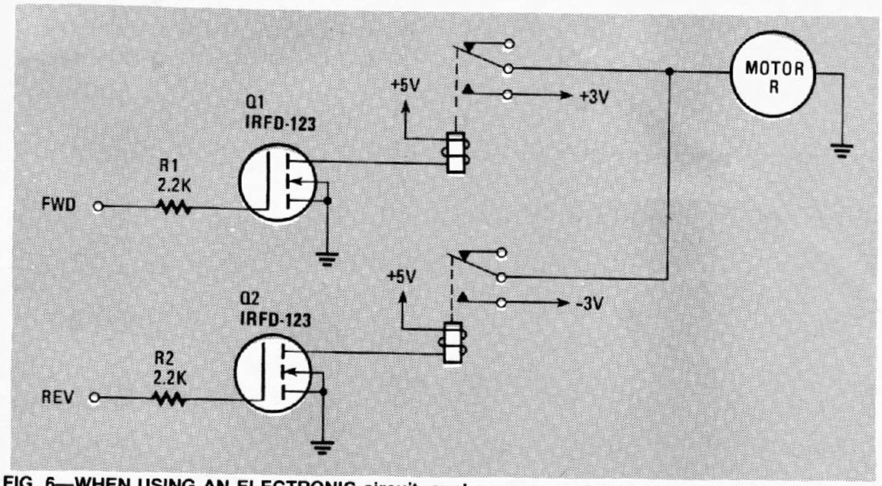


FIG. 6—WHEN USING AN ELECTRONIC circuit, such as a computer, to control motor operation, a simple transistor driver like the one shown here must be used.

are used to reduce the speed of a motor while increasing its torque. They can also be used to change the direction of a motor or to transmit the motor's rotational power into other types of movement. Finding gears that will mount onto the shaft of your particular motor may not be easy. Each motor has its own shaft size and hobby-grade motors tend to posses particularly small-diameter shafts. Most of the generally available gears and pulleys are made for much larger motors. For instance, you can get a number of gears from an automotive supply store, but the chances of them fitting your robot motor are slim.

We've thus far found two supply houses that sell gears in sizes, styles, and types appropriate for robot experimentation. Those are Stock Drive Products (55 South Denton Ave, New Hyde Park, NY 11040) and PIC Design (PO Box 1004, Benson Road, Middlebury, CT 06762). Both are very reputable vendors, and supply extensive catalogs for free. The cost of their parts, though, is not cheap. Yes, the material is high quality, but the cost of a few gears can set your project budget back a few years. I suggest using those suppliers when you absolutely need a particular gear or pulley and there is no other source.

In addition, one of the vendors, Stock Drive Products, has published a very complete manual on mechanical design for non-engineers. That book would be a valuable addition to any robot experimenters bookshelf. It is called the *Design and Application of Small Standardized Components Data Book 757*. It retails for $7.95 in softcover and $12.95 in hardcover. Among other things, the book contains a 51-page section on the mechanics of robots that contains information we have not seen published elsewhere.

Control

Because robots are supposed to move on their own, it will be necessary to develop some control circuits eventually. A computer is not an absolute necessity, but one will make your robot capable of doing a whole lot more. Be that as it may, let's start with a less ambitious control system.

What parts are required to provide at least a minimum level of control? First of all, you're going to need relays if your motors are small DC types. Transistor motor-switches do work, but sometimes they do not provide full power to the motor. Small 5-volt SPDT relays do not take up much room, and are readily available from your local electronics supplier.

To drive those relays you've got to determine what will control the robot. If simple manually-activated switches are used, then you can connect the supply voltage directly through the switch to the relay. When other electronic circuits are controlling the relay, some form of power driver must be used. That can be a simple transistor switch like the one shown in Fig. 6. Each transistor is turned on by applying about 3 volts to the base via the resistor. That will cause current to flow through the relay coil, causing the relay's contacts to close.

When designing your control circuitry, you should keep power consumption in mind. While that might not be critical in the case of robotic arms, mobile units require battery-based on-board supplies. Because of that, use low-power technologies (CMOS, etc.) in your circuitry.

Power supply

Since we've already brought it up, now is as good a time as any to look into the types of power supplies that your robot might need. Once again: with robot arms or other stationary devices, don't worry about batteries; just use an adequate AC power supply. But when your robot must move around, then the only real choice is battery power.

What about the type of battery? Standard, non-rechargable alkaline batteries can power a properly designed system for a surprisingly long time. For example, the author has used two six-volt alkaline batteries in series to provide both a positive and negative supply that has powered six *Robotix* motors for about eleven months! Also, the same supply has been simultaneously powering a CMOS microprocessor circuit.

There are cases, however, that require much more current than alkaline batteries can provide. Those applications require use of lead-acid batteries. That is the type of battery that is used to power your car.

For robotic use, the lead-acid battery has one serious drawback (other than weight). Those batteries can leak corrosive acid if tipped. In some robot applications, that could prove disastrous. In fact, if you plan to use your robot in your home, you should seriously investigate other possible sources of power.

More appropriate are the newer types of lead-acid battery; in them, the acid is in the form of a gel. Obviously, those batteries are much less prone to leakage. Several suppliers, offer many different types of those "gel-cells."

Lead-acid batteries are rated in amp-hours. For instance, if a battery is rated at 4 amp-hours, that means that a robot can draw 4 amps from the battery for one hour, or 1 amp from the battery for 4 hours.

All lead-acid batteries can be recharged. Recharging should be done in a well-ventilated area; the gasses emitted during recharging can be dangerous.

If you decide to go the rechargable power-supply route, you may want to look into the possibility of having the robot charge himself. After all, were you using the robot for security, it would be unfortunate if the batteries were to run down just before the burglar arrives.

Robot kits

There are times when it really doesn't pay to do everything from scratch. If your goal is to learn to program robots, then it might pay you to take some shortcuts so that you can begin using the machine as soon as possible. Buying a pre-engineered kit takes all the worry out of the job. There are several good robots that come as kits. Arctec systems, manufacturers of the *Gemini* robot, sells that robot in kit form. They also will sell you, in kit form, the various subassemblies that make up the robot. Heath's *Hero* series is also sold in kit form, while Rhino Robot's *Scorpion* is only available in that form. And there are many others; for more information see "A Buyer's Guide to Personal Robots" elsewhere in this issue.

There is a lot of satisfaction that goes along with building your own robot. And though things may be a little tough now, this is a brand-new field. In the near future, there will be standard robot buses, standard mechanical interfaces, and even a standard programming language. It looks as if the fun is just beginning. **R-E**