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# Hugging The Wall



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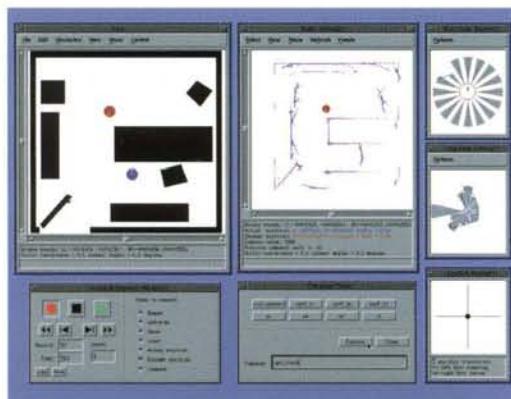
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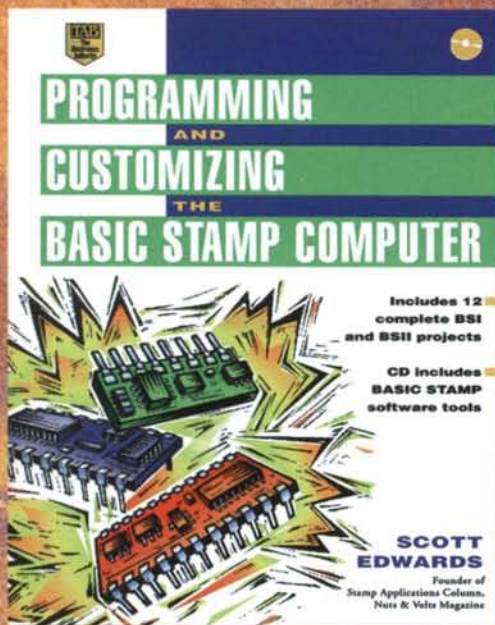


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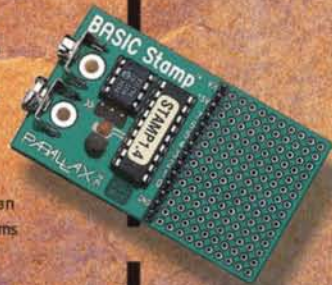
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Robot Science & Technology  
2351 Sunset Blvd #170-253  
Rocklin, CA 95765  
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Robot Science & Technology (ISSN 1096-4754) is published monthly at 4565 Pacific Street, Rocklin, CA 95677; 916.632.1000; Fax: 916.632.9216; info@robotmag.com. No part of this publication may be reproduced by mechanical, photographic or electronic process, or in the form of electronic recording, nor may be stored in a retrieval system, transmitted or otherwise copied for public or private uses without the written permission of the publisher. Subscription inquiries: U.S. and Canada 888.510.7728; all other countries 916.632.1000. Issue price: \$4.95 (U.S.) \$5.95 (Canada). Subscription rates: 6 months \$19.95 U.S., \$29.95 Canada (U.S. funds). Application to mail at Periodicals Postage Pending at Rocklin, CA and additional mailing office. POSTMASTER: Send change of address to: Robot Science & Technology 2351 Sunset Blvd #170-253, Rocklin, CA 95765.

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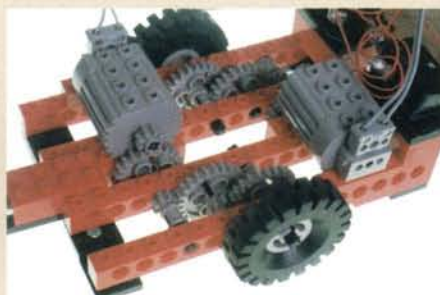
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*Basic engineering principles, gear ratio, torque & power, simple electronic control system. Parts lists, photos, schematics and sources.*



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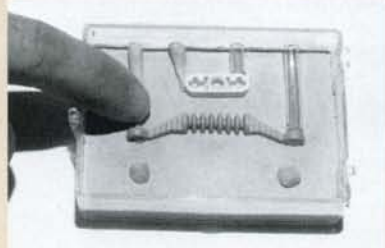
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The total beginner's guide to hand injecting polyester casting resin into a rubber urethane mold. Second in the series of "materials" articles.



*Learn to duplicate a small part, but with greater strength or lighter weight. Custom-make plastic parts to meet your own specifications. A must-read for the serious custom bot builder.*

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### COVER DESIGN: IRIS GILBERT

"Hugging the Wall" shows David Otten's micromouse *Mitee Mouse 5* competing in Boston at APEC-92. There are 82 sensors on those wings!

**Our Mission:**  
 to immerse readers in 21<sup>st</sup> century robotics technology with in-depth reports on real robots and through hands-on adventures  
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by MIT PhDs Joseph Jones and Anita Flynn

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Builders. A great introductory guide for novices, a valuable textbook used with tremendous success at MIT, Vassar and other schools. Recommended for novices and educators. A K Peters, 1993, hardcover, 368 pages, six appendices & extensive bibliography \$48



*Sensors for Mobile Robots*  
by veteran military roboticist H.R. Everett

Here is the most comprehensive yet easy-reading explanation of the theory and operation of both prototype and commercially available sensor systems. Both students and experienced development engineers need this textbook, packed with practical lessons learned from actual use on a variety of robotic vehicles. This is a must-have book for everyone who is serious about

robot sensors. Recommended for R&D, industry, government and academia. A K Peters, 1995, hardcover, 544 pages with as many illustrations \$68

*Navigating Mobile Robots: Systems and Techniques*  
by Borenstein, Everett & Feng

Both professional and hobbyist robot designers face complicated problems such as positioning, real-world navigation, landmark recognition and model matching. This thorough, broad-scope & easily-read resource presents practical solutions for choosing and using a wide array of map-based sensors, dead reckoning optical encoders, dopplers, drive & steering systems, mechanical & optical gyroscopes, magnetics, active beacons, odometry & many more methods of positioning, steering & navigation. A K Peters, 1996, CD-ROM w/ video clips & search capabilities

The A K Peters catalog describes in detail over 70 books



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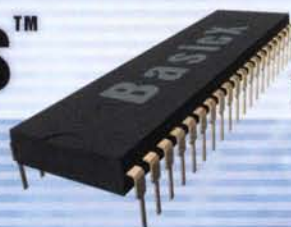
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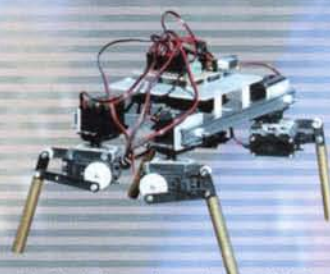
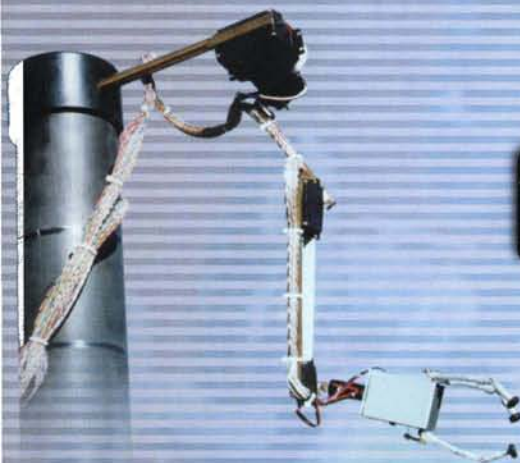
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## ON-CHIP MULTITASKING OPERATING SYSTEM

The BasicX chip has a built-in multitasking operating system that executes Basic language statements. Basic subroutines can be CALLED as normal or now CALLTASKed in parallel. Run hundreds of tasks simultaneously limited only by available RAM. Tasks are like having additional BasicX processors. Tasks can share global variables, perform I/O, network, sleep and alarm, start and stop other tasks and even interrupt on critical events. Complex problems become easy with Tasks. Code sharing allows tasks to utilize common code to save space.



## COMPLETE DEVELOPMENT ENVIRONMENT

The BasicX development system includes an RS485 network, COM port circuit emulator/expansion connector, Expandable SPI Code EEPROM, and bytes of on-chip RAM. The development system is connected to a parallel port for downloading. On most computers, no external power supply is required. A complete BasicX compiler, editor and debugger is provided for easy development. Just write your code and load it. Additional RAM, EEPROM, and I/O interfaces are available. See our web site for details.

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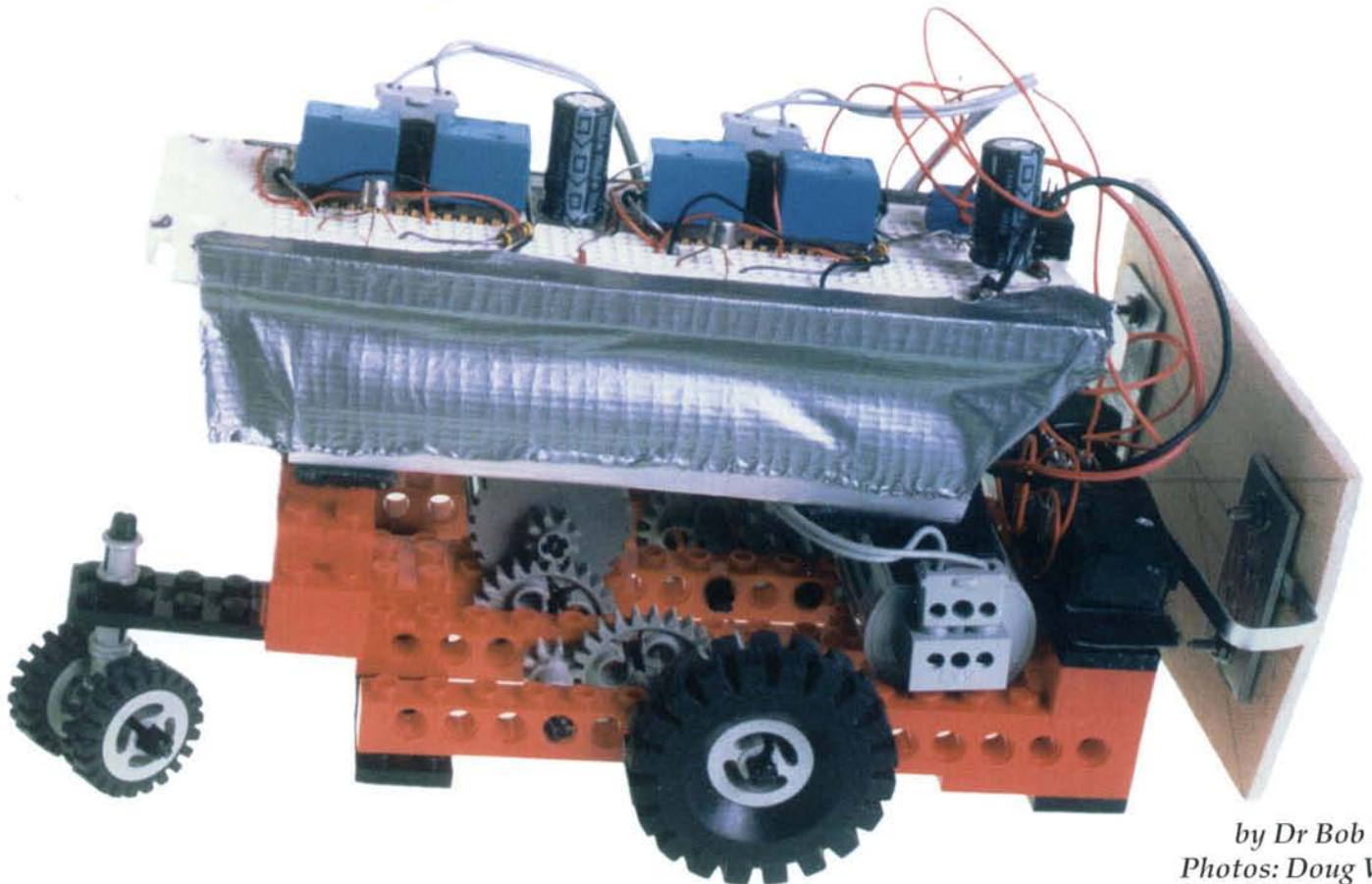


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# TuteBot

## Build and Analyze a Simple Mobile Robot



by Dr Bob Brady  
Photos: Doug Winter

**H**ere we describe in detail the construction and analysis of a simple mobile robot. The work centers on a "TuteBot" style robot as described in the book "Mobile Robots" by Joseph Jones and Anita Flynn (introduced in **RS&T's Premier**). This article complements their work by documenting my experiences, helping you save money by suggesting some alternative parts lists, and providing a way to analyze the performance of your TuteBot.



**B**illed as a simple starter or "tutorial" robot that allows beginners to quickly understand and build basic robots, TuteBot lives up to its name. Anyone with a basic grasp of electrical/mechanical principles can understand and build a TuteBot. For those without: relax, you can probably do it anyway, with the help of this article.

Physically, it is a simple mobile robot with an *analog* electronic brain. It is approximately 21 cm long by 10 cm wide by 14 cm high.

You can construct a TuteBot either by using \$200 worth of Lego™ bricks and motors, or by hacking a \$40 bulldozer chassis/motor/gear-train platform. It is controlled by an electronic brain, which you build using \$50 worth of common parts from Radio Shack or through mail order. (Resources are listed at the end of this article.)

The propulsion system consists of two 3-4 Vdc motors with gear reduction (more on that later) to provide suitable wheel speed and torque. The electronic control system allows our little mechatronic friend to navigate around obstacles or follow a wall.

A beginner should be able to build a TuteBot in eight hours or less. Most likely you will make a few mistakes along the way and have to scratch your head and troubleshoot your way clear of them. Believe it or not, this is one of the joys of robotics. The sense of achievement and self-confidence you get after working your way around your own set of obstacles will more than compensate for any fleeting feelings of frustration you may encounter.

(For younger readers, this article represents a *tour de force* of basic engineering principles. What sorts of things does a mechanical or electrical engineer *do*, anyway? Read on and you will get a flavor for the nature of the work.)

**With a Hacker version, nobody can accuse you of building a kit. You can enter your hacked bot in competitions with impunity.**

### **Let's Get Started: TuteBot Parts List**

First things first. You'll need to gather the necessary parts to build your robot. I offer two versions of the parts list: Deluxe and Hacker. The Deluxe version consists of stock Lego parts, allowing you to follow along the steps in *Mobile Robots*. But it costs over \$200!

In contrast, the "Hacker" version is an order of magnitude cheaper than Deluxe, and requires some minor modifications (but takes less overall effort). It costs about \$90, total. Both versions share a common electronics parts list.

#### **Deluxe Mechanical Parts List:**

*One Lego Technic Resource Set – \$216*


Over 1700 pieces! Includes building blocks for the chassis, motors, gears, cams, shafts, and electrical connections. Also contains plenty of extra parts, battery packs for the motors, and links to build a tank-type track system instead of wheels.

Dear reader, verily I say unto you: do not be like the author and throw money at your projects in a cavalier fashion: purchase the hacker version.

#### **Hacker Mechanical Parts List**

*One model bulldozer kit – \$40*

This kit includes a ready-to-go tank-type track vehicle with a dual motor/gear system. You need only to remove the bulldozer blade (a minimalist hack, but a hack nevertheless). You can completely skip over chassis/gear-train building and go directly to building your electronic circuit. And you can save \$170 in the process!

Try to get the square-shaped 1 kΩ potentiometers with screw adjustments since these are easier to work with on the prototype breadboard. Also, be sure to get snap switches with the longest levers you can find. Micro Switch manufactures the long lever type. 

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# TuteBot

The total cost for the parts listed below should be around \$50. See the end of this article for some good sources.

## Build and Understand the Chassis/Propulsion System

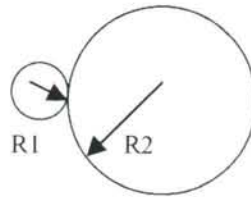
What's so high-falutin' important about this gear train thing, anyway? Why do we need it anyway? Well, the gear train does two things: It reduces wheel speed and increases wheel torque.

### Reducing Wheel Speed

Let's address these items one at a time. First off, let's look at why reducing wheel speed is necessary via a gear train. I measured the speed of the Lego version mobile bot to be about 465 mm per second. With Lego wheels of 43 mm in diameter, this translates to 207 revolutions per minute (rpm, divide the speed by the circumference of the wheel). Motors, however, even under load, will run at thousands of rpm. If the wheels of our bot were directly connected to the motor, you can see the problem: At

5600 rpm, our little lightweight bot will be going over 28 miles per hour and be smashed to bits! Hence, the need for speed reduction.

So how does speed reduction happen with gears? Consider the gear diagram.



The diagram shows smaller Gear 1 with radius R1 meshed with larger Gear 2 with radius R2. The speed of the mesh point equals the rotation velocity of Gear 1 times R1, which must be equal to the rotation velocity of Gear 2 times R2. In other words, the speed of the mesh point is unique; we can express it in terms of Gear 1 or Gear 2. This is all based on the physics of *speed equals rotation velocity times radius* for a point on a rotating object. In math terms, this equals:

$$\begin{aligned} \text{Mesh Point Speed} \\ &= \text{Rotation Velocity 1} \times R1 \\ &= \text{Rotation Velocity 2} \times R2 \end{aligned}$$

or

At 5600 rpm,  
TuteBot will be  
going over  
28 mph!

$$\begin{aligned} \text{Rotation Velocity 2} \\ &\text{divided by} \\ \text{Rotation Velocity 1} \\ &= R1 \div R2 \end{aligned}$$

So, based on the above equation, you can see that by meshing a small gear to a larger gear we can reduce the rotation speed of the shaft attached to the larger gear. This is the principle behind using gear trains to obtain a reasonable wheel speed. The ratio of the output gear radius to the input gear radius is called, appropriately enough, the gear ratio.

### Increasing Wheel Torque

The second reason we need a gear train is to increase wheel torque. Most common hobby or toy electric motors are high speed (several thousands of rpm) and low torque (about 20 g\*cm). In order to provide the torque necessary to drive your robot's wheels, we'll need to increase the torque. We'll prove this later in the performance section. For now, let's look at the mechanics of how this is done.

A gear train not only will reduce wheel speed, but also increase the torque at the same time! Such a deal! To understand why this is so, refer back the little gear/big gear schematic above. If we ignore energy losses such as friction work and heat, then the power input to

## TuteBot, Electrical Parts List (most parts are available at Radio Shack)

- one prototyping breadboard
- one 1-meter length of 26-gauge single-strand (solid) hookup wire
- one battery holder for 4 C-cells
- two 2N2222a transistors
- four 1N4001 diodes
- two 1000 micro-Farad ( $\mu\text{F}$ ) capacitors
- two 0.1  $\mu\text{F}$  capacitors
- two 1 kilo-Ohm ( $\text{k}\Omega$ ) potentiometers
- two 82  $\Omega$  resistors
- two 470  $\Omega$  resistors (all resistors above are 0.25 Watt)
- two lever-action snap switches, SPDT (single-pole, double-throw)
- four 5 V SPDT relays
- one small toggle switch for main battery power, SPST (single-pole, single-throw)

the little gear has to equal the power output to the big gear. This is called the conservation of energy. Energy simply can't be pulled in from the Fourth Dimension; it has to be accounted for and conserved. What is the power of a gear? From basic physics, it's the torque on its shaft times its rotation velocity. Thus, we have:

$$\text{Power In} = \text{Power Out}$$

$$\text{Torque 1} \times \text{Rotation Velocity 1} \\ = \text{Torque 2} \times \text{Rotation Velocity 2}$$

or

$$\text{Torque 2} \div \text{Torque 1} \\ = \text{Rotation Velocity 1} \\ \div \text{Rotation Velocity 2}$$

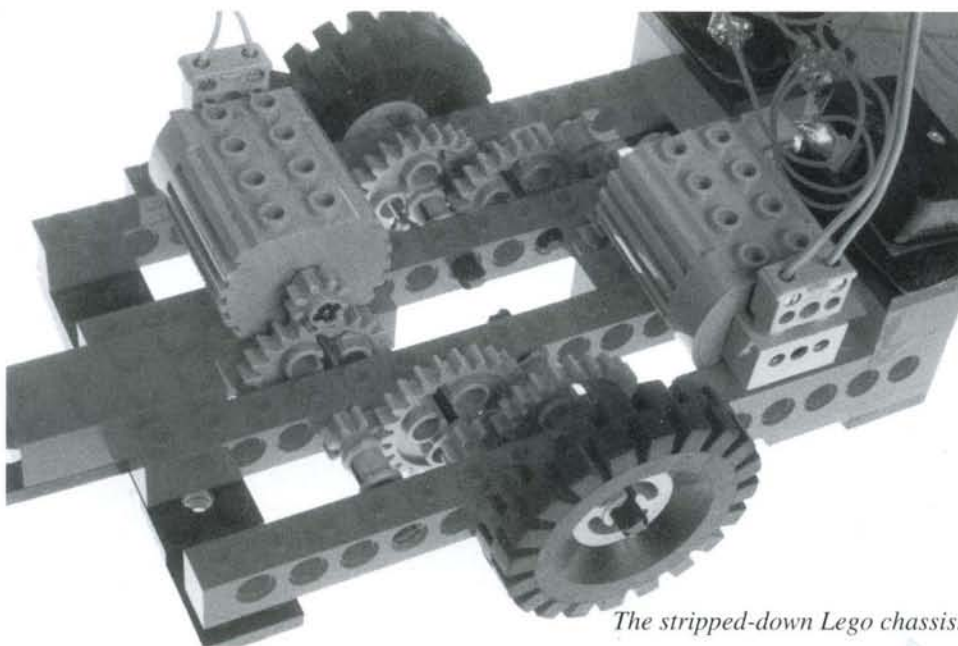
But, from velocity reduction we know that:

$$\text{Rotation Velocity 1} \div \text{Rotation Velocity 2} \\ = R2 \div R1$$

which means

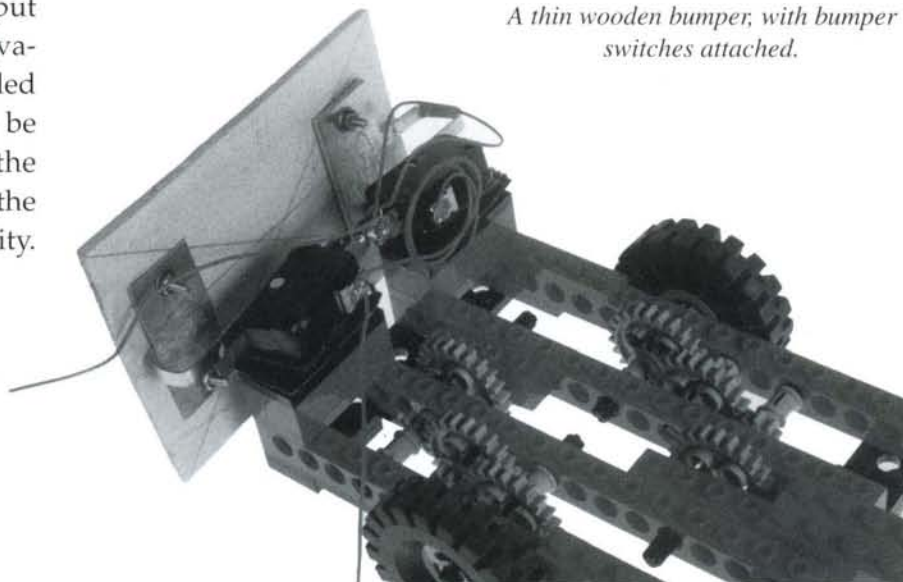
$$\text{Torque 2} \div \text{Torque 1} = R2 \div R1$$

And so, a gear reduction increases the output torque as well as decreases the output speed.



*The stripped-down Lego chassis.*

*A thin wooden bumper, with bumper switches attached.*




## ***Building the Chassis***

If you are going to use the Hacker chassis, then simply remove the bulldozer blade and skip to the electronics section. If you bought the Lego set, read on.

First, look at the image of the chassis below with the electronics removed from it. Here you will see the gear layout and Lego chassis details. You can see the motor shaft has a small 8-tooth gear mounted to it, which in turn rests on a 24-tooth gear directly below it. This larger 24-tooth gear is attached to a shaft with another small 8-tooth gear on the other end.

The configuration is repeated twice: once to another 24/8 gear combo shaft and again to the wheel axle. Use four long Lego bars to mount the motor and insert the gear shaft/wheel axle combinations, as shown in the image. It's best to first use two of the Lego bars to build each wheel gear system, then mount the motors and connect the bars with Lego blocks acting as cross-members to make the chassis rigid. Connect two smaller wheels to a short axle and mount this to one end of the chassis to act as a caster wheel.

You will also need to construct a bumper assembly using the lever switches mentioned in the electrical parts list. I recommend 

# TuteBot

taking the levers and bending them into something of a "J" or hook shape with a pair of pliers. Then set the switches side-by-side and glue or clamp a thin, wooden or plastic bumper onto the levers. You can see the chassis images below and on Page 6 for examples of this. You can then mount your bumper assembly with Velcro to the chassis.

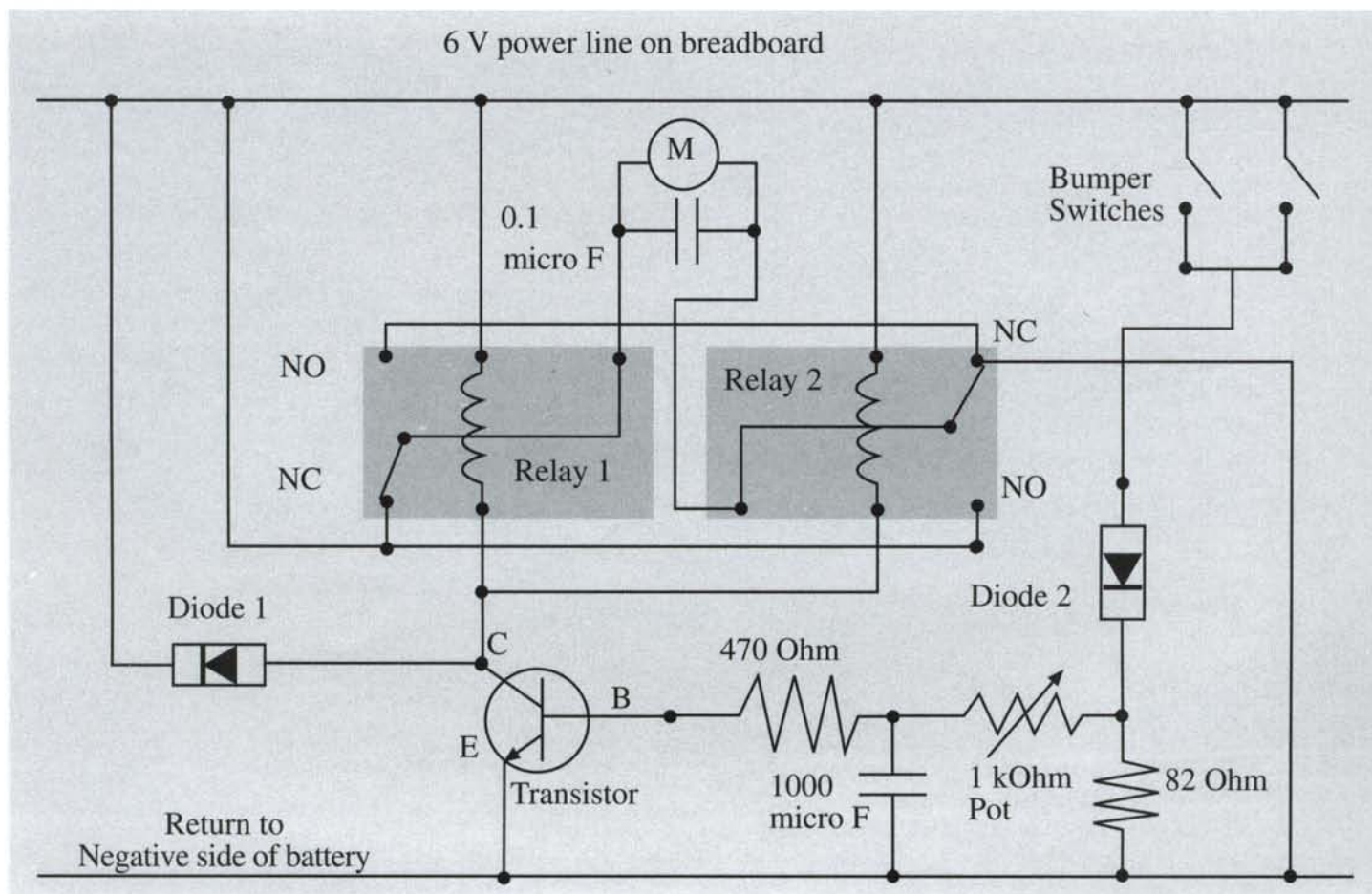
## Build and Understand the Electronic Control System

This discussion assumes the reader is familiar with basic electric circuit theory. Diodes, transistors and relays are used in the control circuit, about which some of you may not be familiar. A simple explanation of them follows: A diode allows current to flow in only one direction, the direction of the arrowhead given in its schematic below. A transistor acts as a switch: If you allow current to flow into its base lead (marked "B"),

then current will be allowed to flow from its collector to emitter leads (marked "C" and "E"). A relay moves a switch when a voltage is applied to its coil connections. These are crude explanations; better ones are given in electronic texts, but these will still allow you to understand the circuit basics.

The electronic circuit is described in detail in the *Mobile Robots* book. I'll outline the fundamentals of it and provide a circuit diagram that may be easier to grasp.

The circuit is actually made up of two identical sub-circuits, one for each motor. An independent circuit is needed for each motor so that one can be powered longer than the other when the bot is backing up from an obstacle. This allows the bot to spin in place before going forward. If the bot did not spin in place, then it would simply back-up, hit the obstacle, back up, hit the obstacle, *ad infinitum*. The schematic below shows one of the sub-circuits.




The circuit schematic is drawn the way it would be wired on a breadboard. The "M" inside a circle represents the motor.

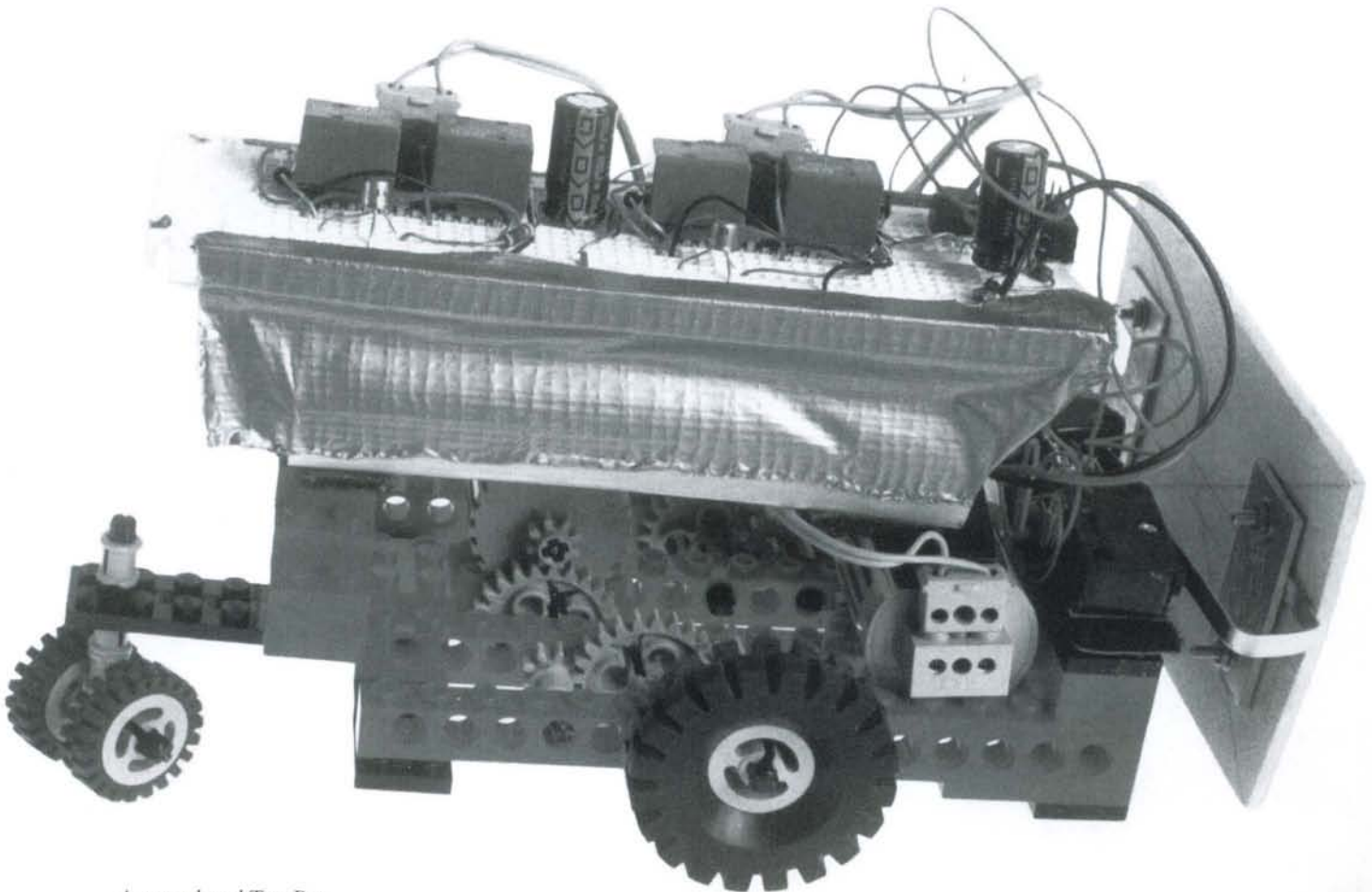
First, wire together one motor sub-circuit. Check the continuity of each connection as you go along, this will save you troubleshooting effort in the long run. Use 26-gauge single strand wire for making your breadboard connections because this size wire fits nicely into the sockets. You would have to tin the leads if you used multi-strand wire to get similar results. (You might find that slightly larger wire, 24 gauge, fits your breadboard better.)

Now, simply connect the +6 V line of your four C-cell battery holder to the top connection line on the breadboard and the ground to the bottom line. Then follow the schematic connections. Be sure to connect the negatively marked lead of the 1000  $\mu$ F capacitor to the ground. As pointed out before, try to get a 1 k potentiometer that has PC board leads (round leads, not the flat prong type). I had trouble getting good breadboard connections with the prong variety.

The circuit schematic shows the normal, or forward, mode of operation. The motor lead at the Normally

Closed (NC) pin of Relay 1 is set high, and the lead at the Normally Closed pin of Relay 2 is set to ground. Now suppose the bot strikes an obstacle and the bumper switches are closed. As long as the bumper switches are closed, current will flow from the power line through Diode 2 and into the transistor base lead. This will cause the transistor to conduct current from its collector to emitter, also enabling current to pass through both the coils of the relays. The relays will switch from their Normally Closed to Normally Open (NO) positions when their coils are passing current, thus also reversing the polarity of the applied motor voltage. The motor will now run backwards.

Now here's the trick: As soon as the motor runs backwards, the bumper switches will break their contacts. However, the 1000  $\mu$ F capacitor will have some stored charge and will continue to pass current to the transistor base. The 1 k potentiometer can be adjusted so that the discharge time in one motor circuit varies from that of the other, allowing the bot to turn as it goes backward. The motor will run backwards as long as the transistor base receives a sufficient level of current from the capacitor discharge loop. 



*A completed TuteBot*

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## TuteBot

Now let's explain the purpose of a few of the circuit components you may have been wondering about. Diode 1 is put in parallel with the relay coils to dampen the voltage spike caused by the rapid collapse of the magnetic field in the coils. The 0.1  $\mu$ F capacitor is placed in parallel with the motor for basically the same reason: to dampen voltage spikes. Diode 2 is used to prevent the capacitor from discharging to the other motor sub-circuit.

After you have built two working sub-circuits, connect them in parallel and you are all set. I mounted the breadboarded circuit to my bot using Velcro. I also mounted the battery pack to the chassis with Velcro. Velcro sets with adhesive backing are ideal for this purpose and cheap too. Enjoy!

### Do a Performance Analysis of Your Bot

Once you have your bot built you may want to quantify how it performs. In order to do this you'll have to know its mass, some of its motor specifications, and make a few assumptions.

One goal would be to determine the gear reduction and power required to operate your bot. First, find its weight. Next, find its speed. You can find its speed simply by measuring the time it takes the bot to travel over a known distance. I used the chrono function of my watch and the number of floor tiles covered (one floor tile = 8 inches in my home). We can use my bot as

an example for calculations:

**Bot Weight = 5.3 Newtons (1.2 lbs.)**

**Bot Wheel Radius = 21.5 mm**

**Bot Speed = 47.5 cm/second**

(Above, you see that "Newtons" are used as the metric measurement of weight. One Newton is the object mass in kilograms multiplied by the gravitational constant of 9.81 mps<sup>2</sup>.)

The torque required to run my bot is the product of the friction force on the tires and the radius of the tires. The friction force, in turn, is the product of the bot weight times a friction factor. A value of about 0.5 is a good estimate between rubber and a smooth floor surface. So now let's find the torque required by each motor:

**Friction Force on Each Drive Tire**

=  $0.5 \times 5.3 \text{ N} \div 2$

= 1.325 N (Newtons)

(Each motor provides for half the friction force, so we divided by two.)

**Friction Torque on Each Motor**

=  $1.325 \text{ N} \times 0.0215\text{m}$

= 0.0285 Nm = 290 g\*cm

(Remember that 0.0285m is my bot's wheel radius)

The Lego motors I used typically can provide only 20 g\*cm of torque output at the motor shaft. Thus:

**Torque Available to Motor**

= 20 g\*cm

**Gear Reduction Required**

=  $290 \text{ g*cm} \div 20 \text{ g*cm} = 14.5$

### Gear Reduction Used

$$= (24/8)(24/8)(24/8) \\ = (3)(3)(3) = 27$$

Dividing the above reduction factors, we have:

### Torque Safety Factor

$$= 27 \div 14.5 = 1.86 \text{ or } 86\% \text{ excess}$$

We can see that I have 86 percent leftover torque that can be used for driving the bot up inclines or to go over more rugged terrain.

Now let's find the power required to drive the bot at its operating speed. Power is defined as force times velocity. So we simply multi-

ply the friction force by the velocity of the bot to find the power output required by each motor:

$$\text{Power Output Required of Each Motor} \\ = 1.325 \text{ N} \times 0.475 = 0.63 \text{ W (Watts)}$$

Assume that the motors are 60 percent efficient, then estimate the power input to each motor required from the batteries:

$$\text{Power Input of Each Motor} \\ \text{from Batteries } 0.63/0.6 \quad 1.0 \text{ W}$$

So the total power consumption of the bot should be around 2.0 W from the battery pack.

## Other Suggested Activities

Build a maze for your bot. In what geometries does it perform best? What modifications can you make to increase its maze-solving time?

Can you build an incline and use the performance equations along with basic physics to predict your bot's speed up the ramp?

Replace the analog electronic brain with a micro-controller. Try using a Basic Stamp from Parallax.

Can you add any additional sensors to your bot? Would you be able to build a light-avoiding or light-seeking bot?

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## RESOURCES

**Electronic Goldmine**  
www.goldmine-elec.com  
800.445.0697

**Newark Electronics**  
www.newark.com  
800.463.9275

**Honeywell Micro Switch**  
www.honeywell.com/sensing/

**Pitsco Lego-Dacta**  
www.Pitsco-LegoDacta.com  
800.358.4983  
(Lego Technic Resource Kit)

**Mondo-Tronics Robot Store**  
www.RobotStore.com  
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(model bulldozer)

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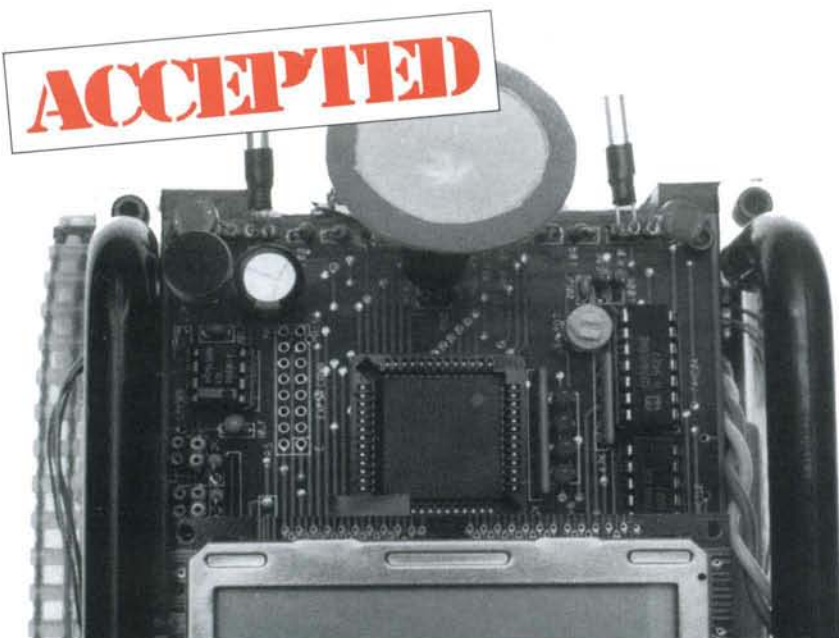
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# Get the Picture!

When it comes to building and operating robots, a picture is worth a thousand words – and a really good picture is worth a couple thousand words. Here at *RS&T*, we want really good pictures and schematics. In fact, we're not interested in an article unless you've got high quality graphics to go with it. Here are some tips for good art.



*We love detailed photos!*

**details, details, details** – Your robot is made up of components – drive train, power plant, sensors, circuit boards, etc. Show us each part neatly arranged – even if you have to take your bot apart to do it.

**neutralize backgrounds** – Taking pictures of the details of robots is difficult enough without having to deal with busy backgrounds. Choose backgrounds that show off your bot in the best light – usually a flat white works best.

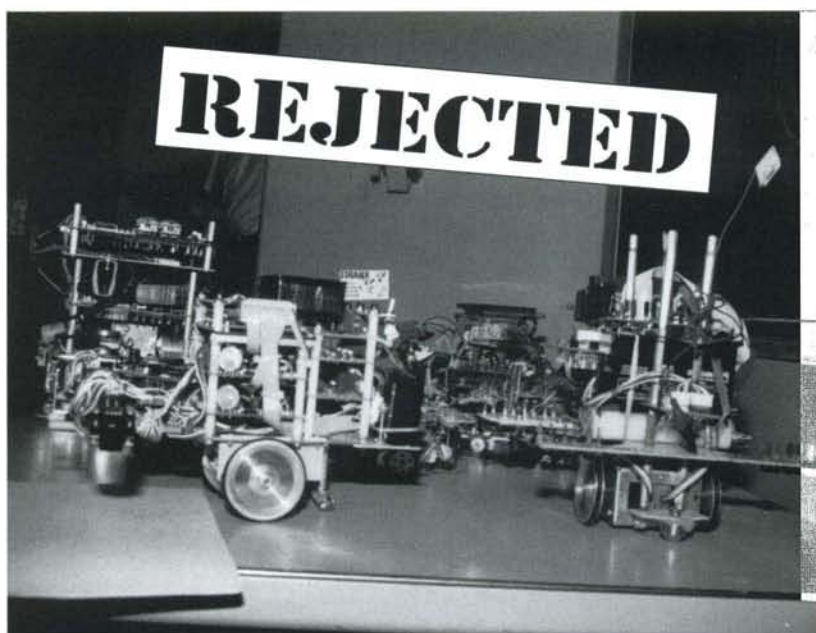
**who is it? what is it?** – Attach captions carefully to each photo. Do not write on the photo itself. You *must* clearly identify (left to right) who and/or what is in the picture.

**we'd rather scan it ourselves** – We prefer color or B&W glossy prints, minimum 4x6 inches. If we need slides or negatives, we'll contact you. Electronic submissions of photos are not acceptable.

**go deep** – When shooting close-ups, we want *everything* in focus. Check your depth of field. We want to be able to read the numbers on the microchip.

**shoot wide** – Nothing makes us crazier than a picture of *almost* the whole robot. When in doubt, shoot wide. We'll crop it.

**cover all the angles** – One of the secrets of photography is to shoot a lot of pictures. This is especially important when shooting competitions. When shooting static shots, get down to eye-level with the robot. Shoot it from the front, back, sides, top and underneath. (See *TuteBot* on pages 6-13.)



*Put this in your scrapbook  
and send us the robot.*

**We'll shoot it**

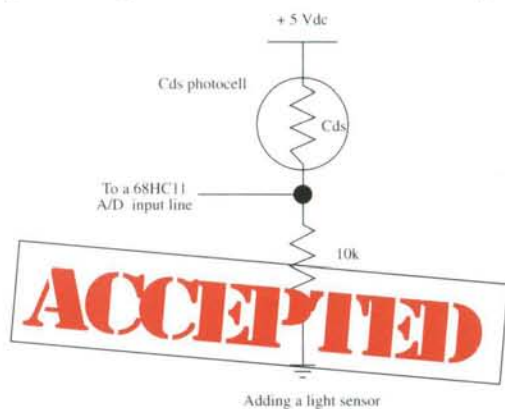


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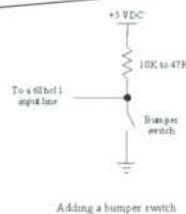


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**write tight**— Good writing is rewriting. *Proofread! Fact check!* Send us your best effort in 1,000 to 3,500 words.

**save a tree** — Send queries and articles by email — WordPerfect or MS Word (PC or Mac) file attachments are preferred; ASCII or RTF files are acceptable.

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he pros said it couldn't be done: They said you could not duplicate small, intricate parts in plastic without professional equipment. Our resident fabrication specialist Rick Hahn took this as a direct challenge.

In this article, Rick shows you how to replicate two small complex objects – a 1/2-inch plastic link and a rack – by injecting polyester casting resin into a urethane rubber mold. All it requires is a minor investment in equipment and chemicals, a little patience, and a lot of good ventilation.

## **Fabrication:**

# Inject Some Fantastic Plastic into Your Next Robot

by RS&T Ltd.

## **Making the Mold – Side A**

- 1** Get a small plastic box or cylinder with *vertical* sides. The container should be about one inch deeper than the objects you plan to cast.
- 2** Lay a half-inch level bed of Plasticene modeling clay in the bottom of the box. Make sure the clay seals tightly against the edges of the box.
- 3** Set the link and rack in the clay bed. Because the link is hollow on one side, just set it firmly on top of the clay with the hollow side down. Because the rack is uniformly shaped on both sides, push it firmly into the clay up to its centerline.
- 4** Make a "sprue" and an air vent for each object. A sprue is a hollow tube for pouring or injecting liquid plastic into the mold. The vent is a channel to let air bubbles escape from the mold as the plastic is injected.
- 4** Cut two lengths of 1/4-inch clear plastic tubing to make the sprues. The tubing (the kind used in aquariums) should be just long enough to firmly touch both the object and the wall of the box. Press the tubing slightly into the clay bed, being careful not to let any clay get into the tubes.

## **SERIOUS REMINDER:**

*These directions are intended as a general guide to injection molding. Be aware these chemicals are flammable and/or toxic. Always follow the manufacturer's instructions explicitly.*

**4** **b** Make two air vents by rolling small pieces of clay into half-cone shapes. Place the narrow end firmly up against each object. Likewise, seal the wide end up against the wall of the box.

Where the sprues and vents are placed against the object depends upon the shape of the object. The sprues should be placed to make it as easy as possible for air to escape through the vents during the injection process.

**5** Make two registration bumps by rolling two small balls of clay and pressing them into the clay bed near the objects. These bumps will ensure that your mold halves will line up correctly when you do the actual casting.

**6** Spray the clay and objects with a light film of a "release agent." The agent prevents the mold material from sticking to the clay or the objects. Rick prefers WD-40 as an all-purpose release agent. There are,

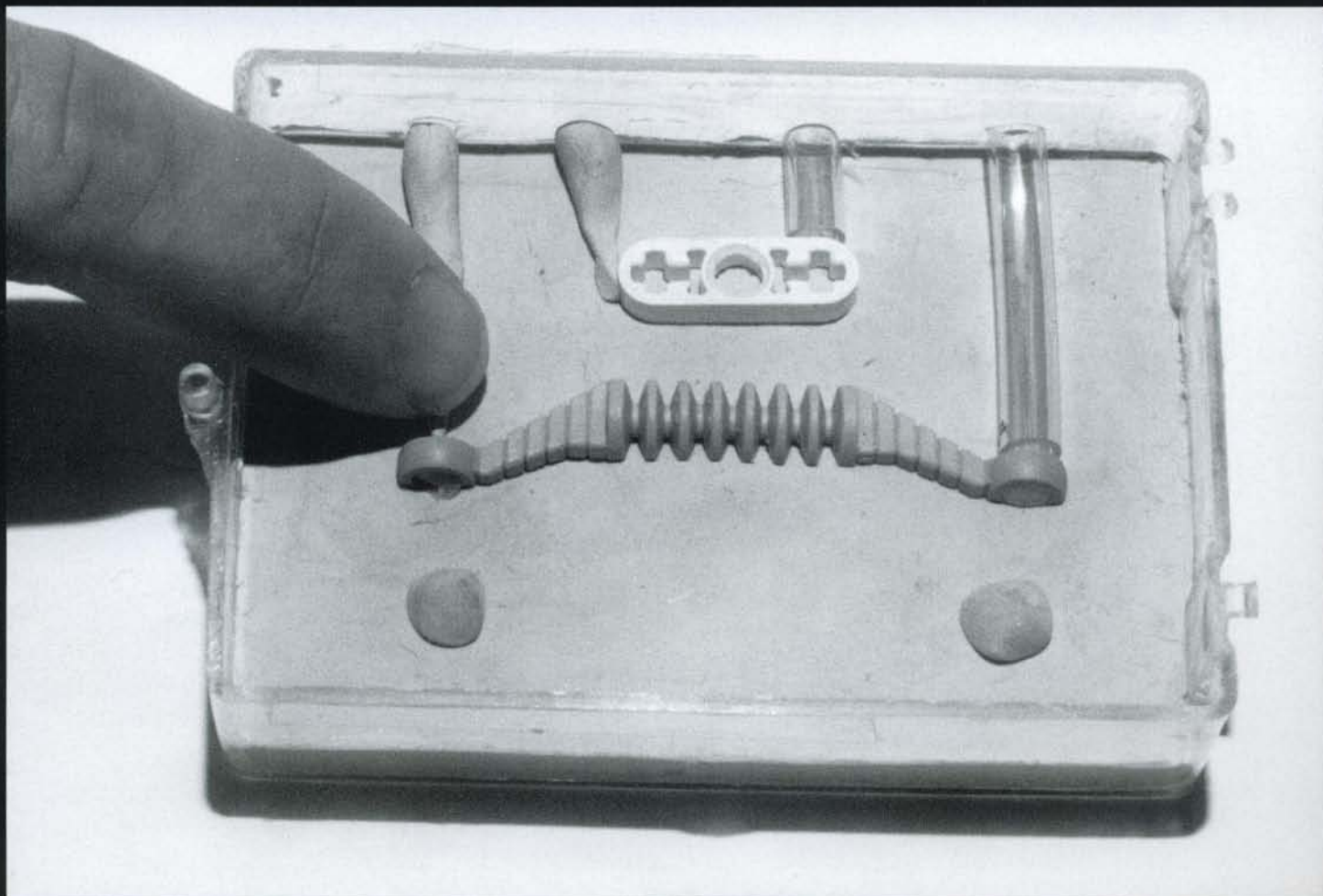
however, commercial silicone sprays made expressly for this purpose, such as Pol-Ease 2300 by TAP Plastics Inc. TAP also makes a wax mold release, but Rick reported that wax is too thick and uneven for use in casting delicate and intricate objects.

While it is important not to use too much release agent, it is equally important that all surfaces be coated evenly. Use a small paintbrush to make sure objects with fine details are completely protected by the release agent.

**7** Mix up enough liquid urethane to cover the entire clay bed and objects by at least 3/8 inch. For this project, Rick used TAP Plastics' RTV (room temperature vulcanizing) urethane rubber mold-making kit, which comes in two cans.

Following the kit instructions, use 1-ounce disposable paper cups to measure the correct amounts of the A and B chemicals in a 4-ounce paper cup. Stir the mold-making material thoroughly but slowly to avoid creating air bubbles.

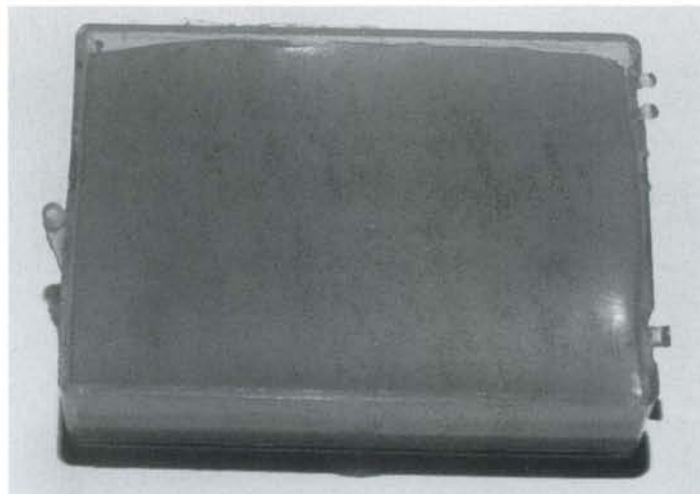
*The clay bed is ready for the pouring of the urethane to make Side A of the mold. The link and the rack are positioned in the clay. The cone-shaped clay air vents are at the upper left. At the upper right are the clear plastic sprues. The registration bumps of clay are at the bottom.*



You can get the cups from any crafts store or pharmacy. Mix the solution with a common wood or plastic coffee stirrer. When properly mixed, the solution should be about the consistency of maple table syrup.

**8** Pour the liquid urethane slowly into one corner of the clay bed. As the liquid flows across the bed and over the objects, jiggle the box gently to level the fluid and help any air bubbles rise to the top.

**9** Set the mold aside in a flat quiet place for at least 48 hours. The room temperature should remain somewhere between 70 to 85 degrees Fahrenheit (21 to 29 degrees Celsius). This is Side A of the mold.



*This is what Side A of your mold should look like while the urethane rubber is curing.*

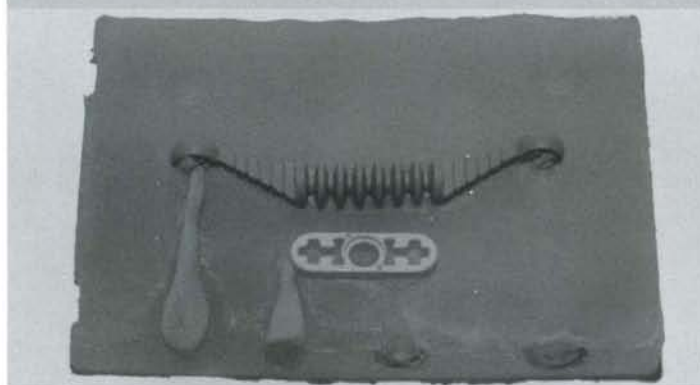
## Making the Mold – Side B

**10** Gently remove the Side A mold half and clay bed from the box after the mold has cured. Sliding a thin blade (such as a dull X-Acto knife) around the edges of the box will help loosen up any sticky spots. The mold and clay should come out of the box easily.

**11** Starting at one corner, carefully separate the clay from the mold. The mold should feel flexible and rubbery.

**12** Make sure the objects (including the plastic sprues and clay air vents) remain embedded in the Side A mold. Remove the clay registration bumps, however.

*This is the Side A mold after it has been separated from the clay bed. Note the objects, the sprues and the clay vents remain embedded in the mold. The clay registration bumps, however, have been removed.*



**13** Put the Side A mold back in the box with the embedded objects facing up.

**14** Repeat Step 6: Spray the mold and objects with release agent. Pay close attention to coating the fine details of the objects.

**15** Repeat Step 7: Mix the A and B ingredients of the urethane rubber compound as before.

**16** Repeat Step 8: Pour the liquid urethane rubber carefully into one corner of the box until the embedded objects are covered by at least 3/8 inch of mold material.

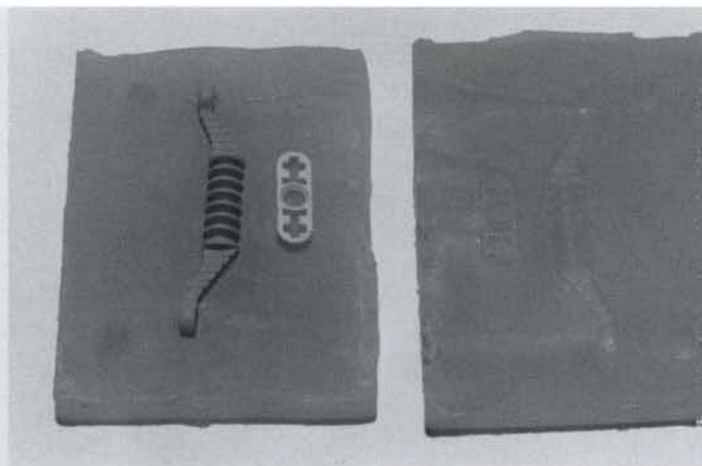
**17** Repeat Step 10: Let the mold cure at room temperature for at least 48 hours. You have just made Side B of your mold.

**18** When Side B is fully cured, carefully remove both sides of the mold from the box. Again, a thin blade may be required to separate the mold from the box.

**19** Flex the mold halves gently until they separate.

**20** Remove the parts and the clay vents from the mold halves. Note that the plastic sprues remain implanted inside the Side A mold.

*These are the completed mold halves with the original objects still in place. Side A is on the right. The clay vents have been removed but the sprues are permanently encased inside the mold. Notice the registration indentations in Side A and the complementary registration bumps on Side B.*



## Injection Casting

Here comes the part they said couldn't be done. Now that you have made the mold, it's time to make your injection castings.

**21** Cut two pieces of stiff, corrugated cardboard to fit the backs of mold halves A and B.

**22** Fit the two mold halves together, making sure the registration bumps align as designed.

**23** Wrap rubber bands around the mold and cardboard – not too loose, not too tight. The idea is to create equal pressure on the mold halves. Make sure not to cover up the sprues and vents.

*Rick holds the mold on its side with the sprues below the air vents. This makes it easy for air to escape out the vents as he injects the casting resin.*



**24** Turn on the ventilation, and clear the room of all small children and pets. Good ventilation is essential here, but it is also necessary to maintain the room temperature.

For this casting, Rick used Clear-Lite polyester casting resin from TAP Plastics. Although the fumes are noxious, this kind of casting resin gives you ample time – about 20 minutes – to mix and inject the liquid into the mold before it begins to harden into plastic. You may wish to don latex gloves during this procedure.

**25** Mix MEKP (methyl ethyl ketone peroxide) catalyst/hardener into the casting resin as instructed. Stir thoroughly but slowly to avoid air bubbles. Try not to breathe the fumes.

**26** Draw up the liquid plastic into a non-needle syringe. Make sure there are no air bubbles. (Syringes are readily available in pharmacies and pet stores for administering oral or external medications.) The outside diameter of the business end of the syringe should fit neatly into the inside diameter of the sprue.

**27** Hold the mold on its side, as illustrated, and inject the resin into the sprues with a slow, steady pressure until the resin

starts coming out of the vents – and there are no more air bubbles. For particularly intricate castings, you may gently massage and jiggle the mold while injecting the resin to squeeze out any trapped air.

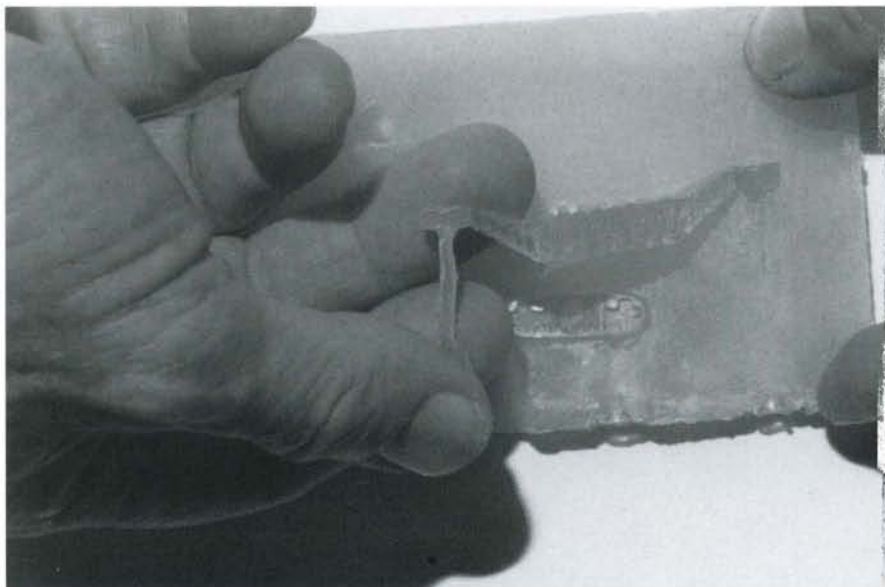
**28** Remove the syringes, being careful not to create a vacuum that sucks resin back up sprue.

**29** Set the mold securely upright on its edge with the sprues and vents on top. Let the castings cure undisturbed at room temperature for at least 24 hrs.

**30** Clean up with common isopropyl (rubbing) alcohol.

**31** When the castings are cured, remove the rubber bands, gently flex the mold, and peel the two mold halves apart. The castings should come out as easily as the originals.

**32** Use an X-Acto knife or a Dremel tool to carefully trim or sand off the excess plastic left on the castings from the sprues and vents.



The near-colorless plastic casting lifts easily out of the mold. The excess plastic between Rick's thumb and finger will be trimmed to complete the fabrication process.

With proper care, your mold can be used over and over again to make multiple, identical parts.

Now that you know how to make your own molds to create your own castings, we'll leave the rest up to your imaginations. If you use this technique in building your next robot, send us pictures and tell us how it worked for you.

In an upcoming issue, Rick Hahn will demonstrate how to use fast-curing polyurethane resin and microspheres to replace a heavy metal gear with tough, ultra light-weight plastic.

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## MATERIALS LIST:

- Small plastic box(es) or cylinder(s) with perpendicular sides – any craft store
- Plasticene modeling clay – less than \$1 for a 1x1x5-inch bar at most craft stores
- 1/4-inch clear plastic tubing (the kind used in aquariums) – 10 cents per foot at pet stores
- Plastic syringes (without needle) that fit inside the tubing (these syringes are commonly found in pet stores or pharmacies for dispensing oral or external medication) – about \$1.50 each
- 1 quart kit (two cans) of TAP Plastics RTV urethane rubber molding material – \$22.15
- 13 ounces WD-40 (hardware store) – \$3.49
- OR:
- 14 ounces TAP Plastics Pol-Ease 2300 silicone spray – \$12.60
- 1 quart TAP Plastics Clear-Lite casting resin – \$10.75
- AND
- 0.5 ounce TAP Plastics MEKP catalyst/hardener – \$1.45
- disposable paper (not plastic) measuring cups (1 oz. and 4 oz.) – craft store or pharmacy
- disposable plastic or wooden coffee stirrers
- assorted rubber bands
- scrap corrugated cardboard

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# Discrete Circuits, Flashy Logic

A tutorial for breadboards introducing Ohm's Law

*You may be a genius with genetic algorithms, data structures and computers, but can you build your own electronics?*

**A**t one time or another, every practical roboticist needs a hands-on introduction to practical electronics. So we compiled this tutorial to help students get started. (Frankly, a lot of us could use a review of the basics, now and then.) No soldering is needed, and the math is simple arithmetic.

This tutorial's objectives are to familiarize the experimenter with breadboarding, to introduce some DC circuit principles, and to predict what happens to volts (V) and ohms ( $\Omega$ ) when we install or substitute discrete components.

("Discrete" components are individual parts like resistors and transistors, as opposed to "integrated" components like computer CPUs and amplifier IC chips.)

Today we'll train using a small breadboard, a hand full of common electrical parts, and a common 9 V battery. You'll need a meter to verify that your components work, to detect voltage, and measure resistance. (I use a Radio Shack digital multi-meter and I always rely upon retractable

hook leads for convenience.) I also suggest using a lead bender, although you could bend leads with a needle-nose pliers. You'll also need to strip the insulation from thin wires. (I use a combination crimper/stripper tool, rather than a pocket knife, to avoid nicking wires and stripping fingers.)

About your breadboard: Some are small and cheap, some are large, modular and expandable, with easily configured power supply pegs. Here, I'm using the cheapest thing from Radio Shack. Note that the holes in the breadboard follow a pattern. The top row holes are all electrically connected (I connect my power supply's positive lead here). The bottom row holes are also connected together (I connect my power supply's negative ground" lead here). My board (illustrated here) has five rows near the top, which are connected vertically. That is, each column of five holes is connected electrically. There are also five rows near the bottom which are similarly connected. Check it out yourself with your ohmmeter.

## Parts List:

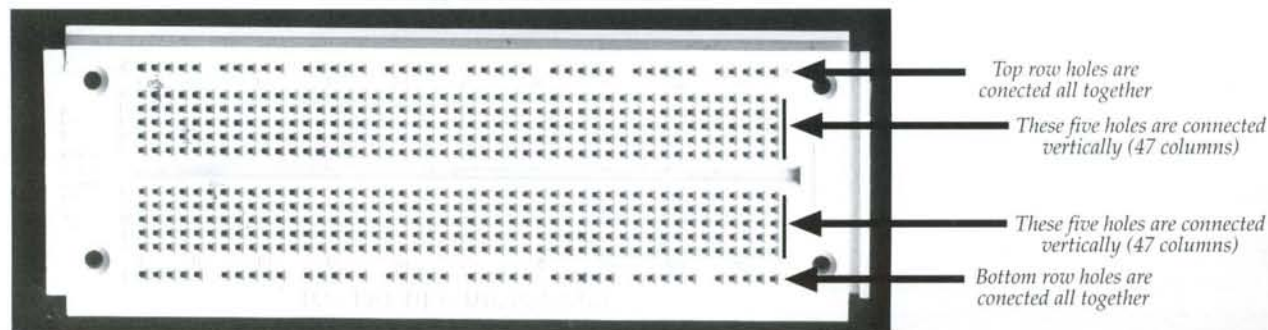
- Solderless Experimentor's Breadboard
- 9 V battery and battery snaps with leads
- 22 gauge solid single strand hookup wire
- Resistors, 1k, 10k, 4.7k (get at least 2 of each)
- Zener Diode, rated at 5.1 Vzener
- Light Emitting Diodes, rated at 5 V (1 or 2 will do)
- NPN Silicon Switching Transistors, 2N222 or similar (at least 2)

## Tools

- Wire Stripper
- Wire Cutter
- Needle Nose Pliers
- Volt-Ohm Meter
- Lead Bender template (optional)

## Free Catalogs for Tools & Parts

- Tech America - 800.877.0072
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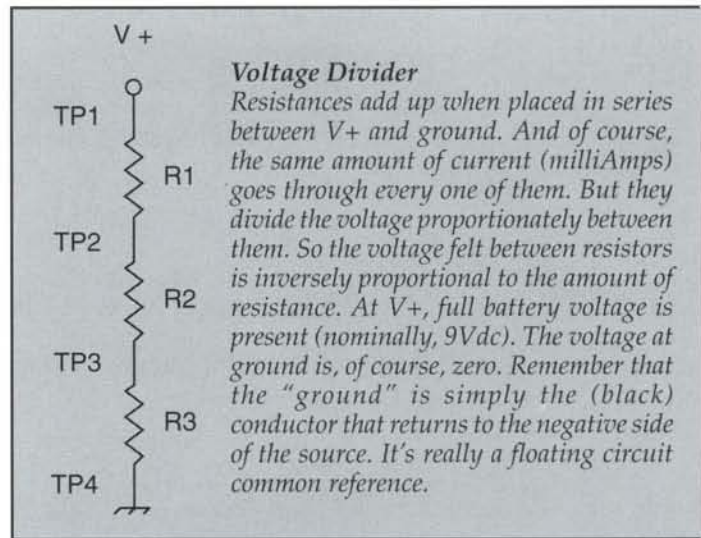


Since most logic circuits are typically designed for 5 volt "highs" and 0 volt "lows," we'll start by constructing a simple voltage divider that shows how to use resistors to drop voltage proportionately in a series. But here's a question: won't the output of our voltage divider drop as the battery gets weaker? Why yes, of course. So to solve that problem, we'll build a zener diode voltage regulator. This voltage regulator will keep our voltage reasonably steady at about 5 volts, even as our battery wears down.

(In future issues, we'll concentrate on building and controlling more sophisticated power supplies. But for this article, we'll concentrate on getting your feet wet [or your hands dirty] with simple transistor logic gates.)

Then, we'll build some transistor logic gates and test their truth tables. We'll use transistors to assemble the following gates: OR, AND, and NOT. You can then combine these basic circuits to also make NAND (not-and), NOR and XOR (exclusive OR) gates on your own.

To build all these circuits, the parts will cost about \$15, and the breadboard may cost a little more than that. You



*Sure, you could build these circuits in 10 minutes and watch the pretty lights flash. But TAKE MEASUREMENTS and DO THE MATH to really understand what you're doing.*

could scavenge your old radios, order from the catalogs listed at the beginning of this article, visit your local electronic hobby or surplus stores, telephone your order, or just go to your nearest Radio Shack. See the Parts List at the front of this article.

A few notes to make this lesson a little easier: First, tidy

up your bench top (or kitchen table), put a trash can nearby, and keep a box on the bench to toss parts that you decide not to use. I also keep a notebook computer nearby, running a spreadsheet program, so I can make calculations quickly, and to re-run equations when I start thinking, "what if I change this circuit like so..." Also, read over the sidebars on bending leads, cutting leads, and grounds before continuing. For reference, the resistor color code is on page 56.

### Let's get going.

**WARNING:** Never "short out" a battery by touching its output connections together. The battery will overheat quickly, and could expel harmful vapors or even explode and burn. Respect all batteries, even the small ones.

Our transistor circuits need a power source that can supply at least 1 V more than the input logic signal, but we can use the same battery for both purposes on our training circuit. The voltage divider will keep the positive transistor voltage (called V+) above the signal source voltage (called Vin). Your multimeter, logic circuit, and battery can all connect to the same cir-

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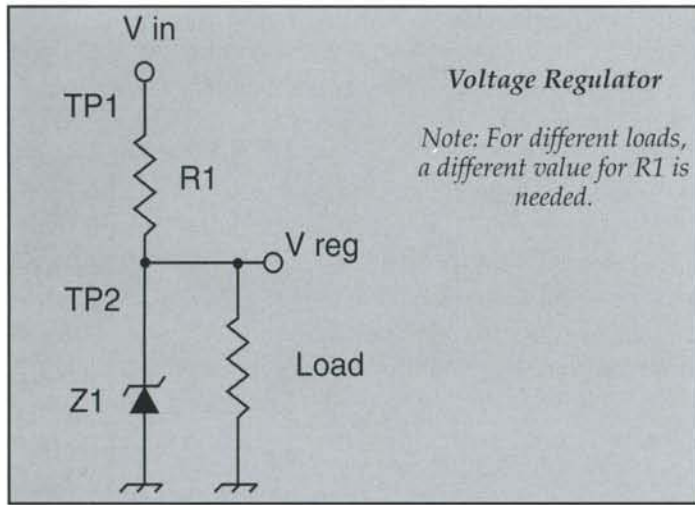
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**Ohm's Law: Voltage,  $E$ , is equal to the current,  $I$ , times the resistance,  $R$ .**

**The formula for Power,  $P$  (watts) is:  $P = I \times E$**

cuit common ground. That is, all our "grounds" will connect to the bottom row of the breadboard (including the negative pole of the battery and the black test lead from our meter).

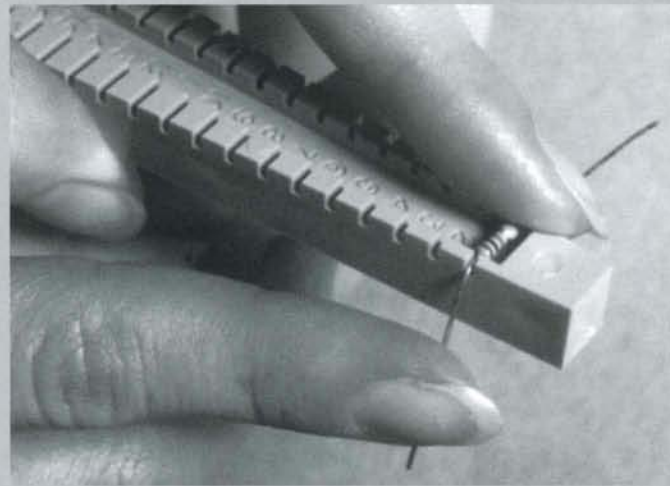
For this project, we need a source of only about 6 to 9 volts that can support a tiny current draw (a few milliAmps).

(Point to remember: Voltage is the electromotive force (EMF) or "electrical pressure" supplied by the source, while current is the electron flow demanded from the source and flowing through the circuit.)

So let's just use a 9-volt battery to supply our circuit. First, we'll make a resistor-based voltage divider to provide two voltages; the 6-9 volts that the transistor circuits need (we'll call this "V Plus" or V+) and the 5 volts needed for the logic signal inputs. Simply hook the battery to three resistors of identical value. Place your meter's black (negative) lead on the common (ground) conductor of our simple voltage divider circuit, and read the voltages by placing your red lead at each of the test points in the circuit, TP1 - TP4. The voltage will drop proportionately to the resistive value of the load between your red and black leads. My first circuit shows three resistors of equal value (10k each), so each resistor in the series will drop one third of the supplied voltage.

My battery gave 9 V at TP1, and 6 V at TP2, 3 V at TP3, and 0 V at TP4.

To gain some understanding, you can try resistors of different sizes, and pre-calculate the expected voltage before measuring it. And for a better understanding, use Ohm's Law and the Power Formula to determine how much power is dissipated by each resistor.



*Push on the lead, not the component.*

## Bending Leads

For reliability and form fitting, *do not* bend leads by holding the lead in one hand and pushing the component. This can cause micro fractures inside the component, leading to intermittent failures (which are frustrating to troubleshoot). Also, do not use common needle nose pliers: The sharp edge can nick the lead, which actually does affect some high frequency circuits. I make a note of it here because nicking conductors is, at least, a bad practice. It is designed to hold the component and root of the lead in place, while you bend the remaining lead around a slightly rounded edge. Lead benders come in different sizes, to accommodate different size components (1/4 watt, 1/2 watt, etc).

Sometimes, you'll want to mount components vertically to save space. In this case, bend the lead around a round object, like the shaft of a jeweler's screwdriver.

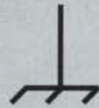
## Cutting Leads

Most cutters have two beveled edges. I prefer to use "flush" cutters with only one bevel. This let's you get a fraction of an inch closer to a component if needed. But be careful when cutting leads, because the bevel can shoot the cutaway portion across the room, to be lost until you crawl on hands and knees to find it.

## Starting at Ground Level



Earth Ground,



Chassis (not earth) Ground

An important but commonly misunderstood concept in electronics is called “ground.” Part of the reason for the misunderstanding may be that electrical home wiring and “black box” electronic wiring are not color-coded the same. Also, there is a big difference between the different situations we call “ground.”

- Earth ground is typically a long steel plumbing pipe on the side of your house.
- Chassis ground is where the power supply is “grounded” to the chassis, such as in a car.
- Circuit common is where voltage is measured in relation to a “floating reference” like the negative side of a battery.

While breadboarding these circuits, your “ground” will actually be the negative side of a common battery. Obviously, this is NOT the same as the earth ground you’ll find at your wall outlets.

**SIDE NOTE:** Even earth grounds differ from one another: The mineral-rich soil between two buildings’ ground pipes may cause a “difference of potential” (voltage) between building grounds. This can be a problem with long circuits, like a computer network between buildings.

I suggest that you think of ground as being a return conductor to the power supply (in this case, a battery). This return conductor *must* be there, or else the electrons can’t travel in a complete “circuit” from the negative end of the battery to the positive. And remember that your ground wire must have a conductor at least as thick as the “power line.” Finally, to keep electronic logic circuits isolated from electrical motor noise, you may want to use completely different power supplies for the logic and motor circuits.

Try adding resistors in the series. And be sure to experiment with resistors of different values. For instance, if you connect a 1k resistor and a 10k resistor end-to-end between V+ and ground, the total resistance in the series would be 11k, and the voltage felt after the 1k resistor would be 10/11 of V+.

Finally, place resistors in parallel, and discover that electrical current will divide itself, to travel through each resistor in inverse proportion to that resistor’s value. And be sure to measure the total circuit resistance. You’ll discover that most of the juice flows through the smallest resistance. The result: when placing resistors in parallel, the total circuit resistance is less than the smallest resistor in the circuit.

Don’t rush past that last statement. Demonstrate it to yourself and use Ohm’s Law to understand how resistive current develops voltage.

### The Mathematics of Zener Voltage Regulators

Let’s build another tiny circuit that requires some simple math to make it work. This one consists of your battery, a zener diode and some resistors. This is a zener-based voltage regulator. It will keep its output voltage at a designated level (say, 5 V), even as the battery loses energy. (Of course, once the battery drops below 5 V, the circuit will not have enough energy to work with.) This regulator isn’t robust or sophisticated, but as a training exercise in using breadboards, components, meters and DC formulas, this circuit will work just fine.

Diodes are all polarized, allowing current flow in one direction only (unless you blow them up by surpassing their rated “breakdown” or reverse voltage).

But this particular type of diode, a zener, will allow electron flow over a designated amount (called  $V_{zener}$ ). Thus, a zener diode with  $V_{zener}$  of 5.1 V will allow the circuit to feel 5.1 volts.

For this exercise, you can simulate a circuit’s load by connecting a resistor in its place. So, to select the proper components, you must know (or estimate) the resistive value of the load. To demo the circuit, I used a 1k resistor as a load.

**WARNING:** DO NOT apply power until you double check for these several things:

- The diode must be inserted in the correct direction.
- The resistor’s value must be calculated fairly accurately.
- Once you connect the 9 V battery, finger-check R1 and the zener diode for overheating. If you can’t comfortably touch them, disconnect power and check for faulty lead connections, backward diode insertion and out-of-bounds resistor selections.

*Continued on Page 56*

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# Silicon Valley's Best and Brightest Take on Tech Challenge 98



by Tom Durkin

It was the last, few, near-vertical inches of the cable that defeated most of the homemade robots. While some of the bots came heart-breakingly close to scoring, others couldn't even make it that far – they fell off the cable, disintegrated on start-up, or just hung there and fried their motors, going nowhere fast.

The scene was the 11th annual Tech Challenge in San Jose, Calif., April 1st. Sponsored by The Tech Museum of Innovation ([www.thetech.org](http://www.thetech.org)), the contest was a three-ring circus of excitement and creativity as hundreds of high school, middle school and elementary school students competed simultaneously on three separate platforms.

This year's challenge was to design and build a cable-climbing device modeled after robots that perform safety inspections of suspension bridges. One of the world's most famous suspension bridges is San Francisco's Golden Gate Bridge, located about 50 miles north of San Jose.

## Just the Specs...

The mission this year was to build a cable-climbing robot that could traverse a 3/16-inch stainless-steel cable strung loosely between two poles of unequal height placed 12 feet apart. The poles were 4 feet and 7 feet 7.5 inches high, respectively. The task was to climb up the cable to the top of each pole and trigger a sensor plate that lit up a bright orange beacon.

Each team had three minutes to light up both beacons.

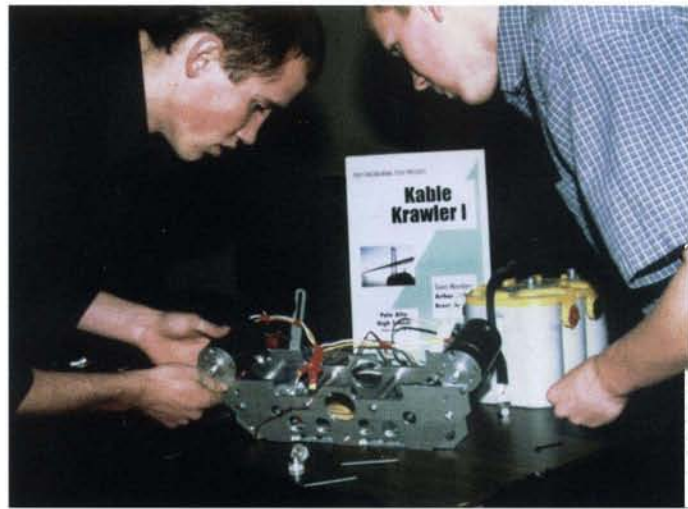
The bots were limited to 10 pounds maximum, but tethered, DC power supplies were allowed offboard and were not counted in the weight limit. Almost all of the entries chose off-board power plants.

## Real-Life Robotic Relevance

Located in the heart of the Silicon Valley, The Tech Challenge is a unique tournament that poses a new design and fabrication problem each year that relates to real-world robotics.

Last year's record-breaking competition challenged more than 1,000 youngsters to emulate the impact landing of Mars *Pathfinder* and deployment of the *Sojourner* rover.

660 students on 162 teams competed. "It's encouraging that we're seeing more and more girls in the competition," Tech staffer Gloria Chun Hoo told *RS&T*. On the roster of prize-winners were eight all-male teams, six all-female teams, and four coed teams.



### And the Winners Are...

There were three grand-prize winners for best overall performance and team spirit – one for each grade division. The robots were judged on speed, reliability, design methodology and creativity of fabrication. Also, new this year, the teams were required to undergo a pre-contest interview with the judges and submit a written record of their R&D process.

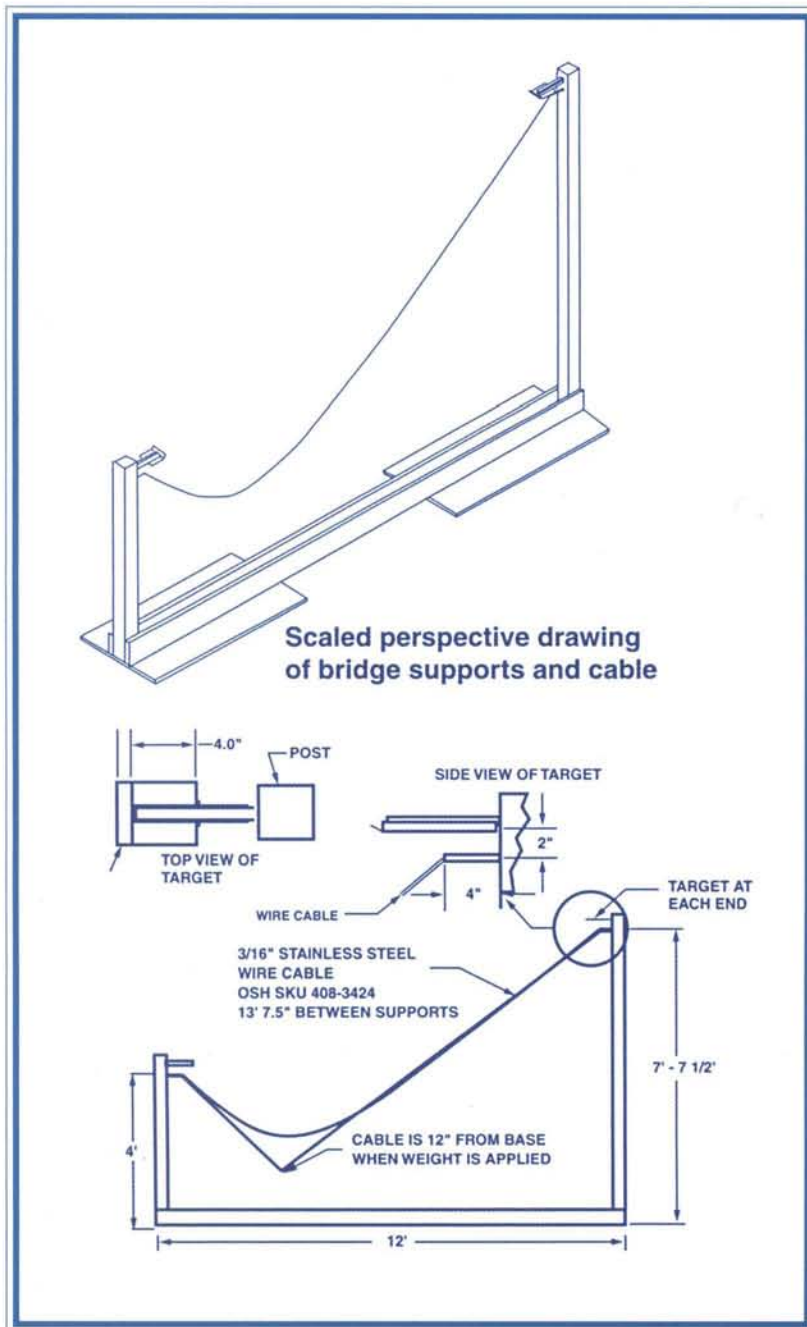
In addition to prizes to the runners-up in the grand prize category, the judges gave awards for fastest, most autonomous, most creative, most reliable, best team spirit, most technologically innovative, best design methodology – and most spectacular failure.

To create as many winners as possible, no team was allowed to win more than one award. If a team triumphed in more than one category, it was presented with the more prestigious prize, and the next best team took home a lesser trophy.

Prizes ranged from cold cash to T-shirts and other goodies to an experiential visit to a high-tech clean room where computer chips are manufactured. Besides the official Tech Challenge prizes, Intel, Advanced Device Microsystems, Adobe Systems, Cirrus Logic, the San Jose Rotary Club, the McCarthy Family Foundation and KPIX-TV also contributed to the jackpot. (To see a list of the winners go to: [www.thetech.org/exhibits\\_events/competit/tech\\_challenge/1998/](http://www.thetech.org/exhibits_events/competit/tech_challenge/1998/))

Given the level of excitement and enthusiasm that permeated this extremely well organized event, there really were no losers.

**RS&T**



# Winning Isn't Everything



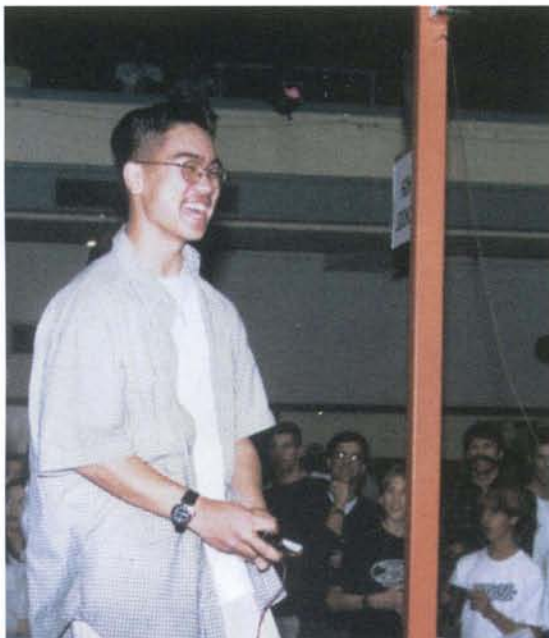
Team Voltron (left to right): James Weingart, Vinh Do, Reagan Jaculina

yelled Vinh Do jubilantly as his team's robot, *Voltron*, blasted through the 3-minute Tech Challenge in a blazing 3.97 seconds.

Although, ultimately, they didn't win, the three ecstatic young men from Mt. Pleasant High School – a math and science magnet school in San Jose – definitely had the winning attitude.

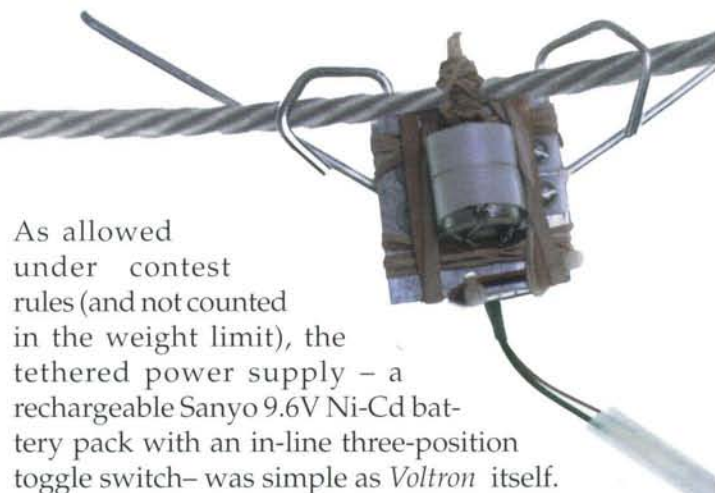
"We KISSed it!" Reagan Jaculina told *RS&T* that the team had followed their mentors' advice: "Keep it simple, stupid."

On a scale of 1 to 10, *Voltron* was a zero on form, but it was a 10 on function. The bot's design was elegantly simple and efficient: a motor hacked from a Radio Shack remote-control toy, a few pieces of scrap metal, and a whole lot of rubber bands.



"Thank you, God!  
Thank you, Radio Shack!"

Facing a 10-pound maximum, *Voltron* weighed in at a svelte 6 oz. on the precision scales at *RS&T*'s secret testing laboratory in the Silicon Foothills east of Sacramento, Calif.



As allowed under contest rules (and not counted in the weight limit), the tethered power supply – a rechargeable Sanyo 9.6V Ni-Cd battery pack with an in-line three-position toggle switch – was simple as *Voltron* itself.

Once the team agreed upon a design that worked, "It took us five minutes to build it, and two days to test it," said team member James Weingart.

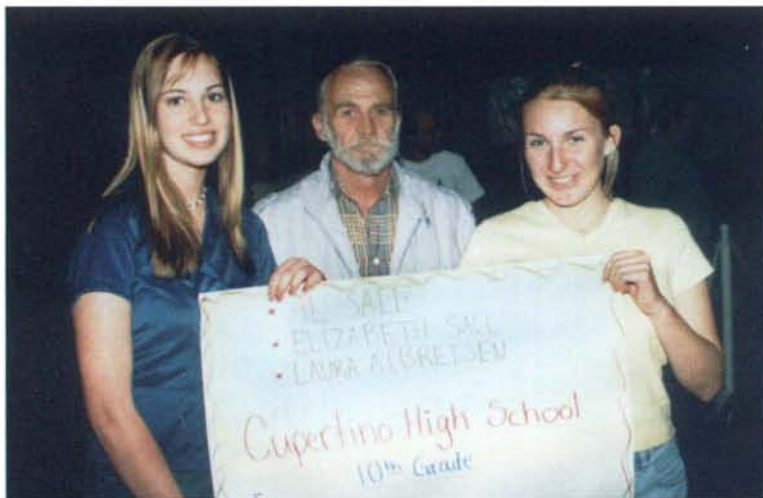
*Team Voltron* didn't win, but they didn't fail either. They did meet the challenge, and that was a win in itself. If anything, the fact that *Voltron* performed so well and still didn't take top honors was an indication of just how tough the competition was.

**RS&T**

Spread Photo: *Voltron* on the cable.

Right: Reagan controlling *Voltron*.

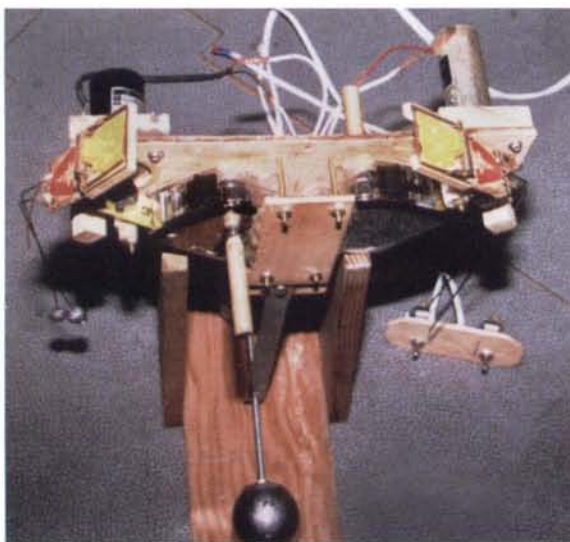
# INGENIOUS INGENUUES



In a field almost completely dominated by men, two young women – Elizabeth Sall and Laura Albretson – from Cupertino High School nailed the Most Creative Design award at Tech Challenge '98.

While virtually all of the 162 robots in the contest were self-propelled, Sall and Albretson's bot didn't go anywhere at all. Instead, it launched two tentacles up the cable that set off the signal beacons.

With advice and spare parts from Elizabeth's grandfather Al Sall, the girls spent "hours and hours" a day



for five weeks testing and discarding various designs until they finally got one that worked.

The chassis of the robot was made of wood. Two metal balls attached to the chas-

sis served as counterweights to lower the center of gravity for balance and to stretch the cable taut for the tentacles.

The tentacles were heavy-duty tape measures with the return springs removed. They were driven by two old DC motors Al Sall donated to the cause. Like the counterweights on the chassis, two pair of small counterweight balls on the tips of the tentacles kept the tentacles on track up the cable.

Finding a better use for mousetraps, Sall and Albretson attached the spring-loaded devices to

the ends of the tape measures to ensure they hit the sensor plates with enough force to light up the beacons.

The tethered off-board power supply was a 12V lead-acid battery made by Hitachi.

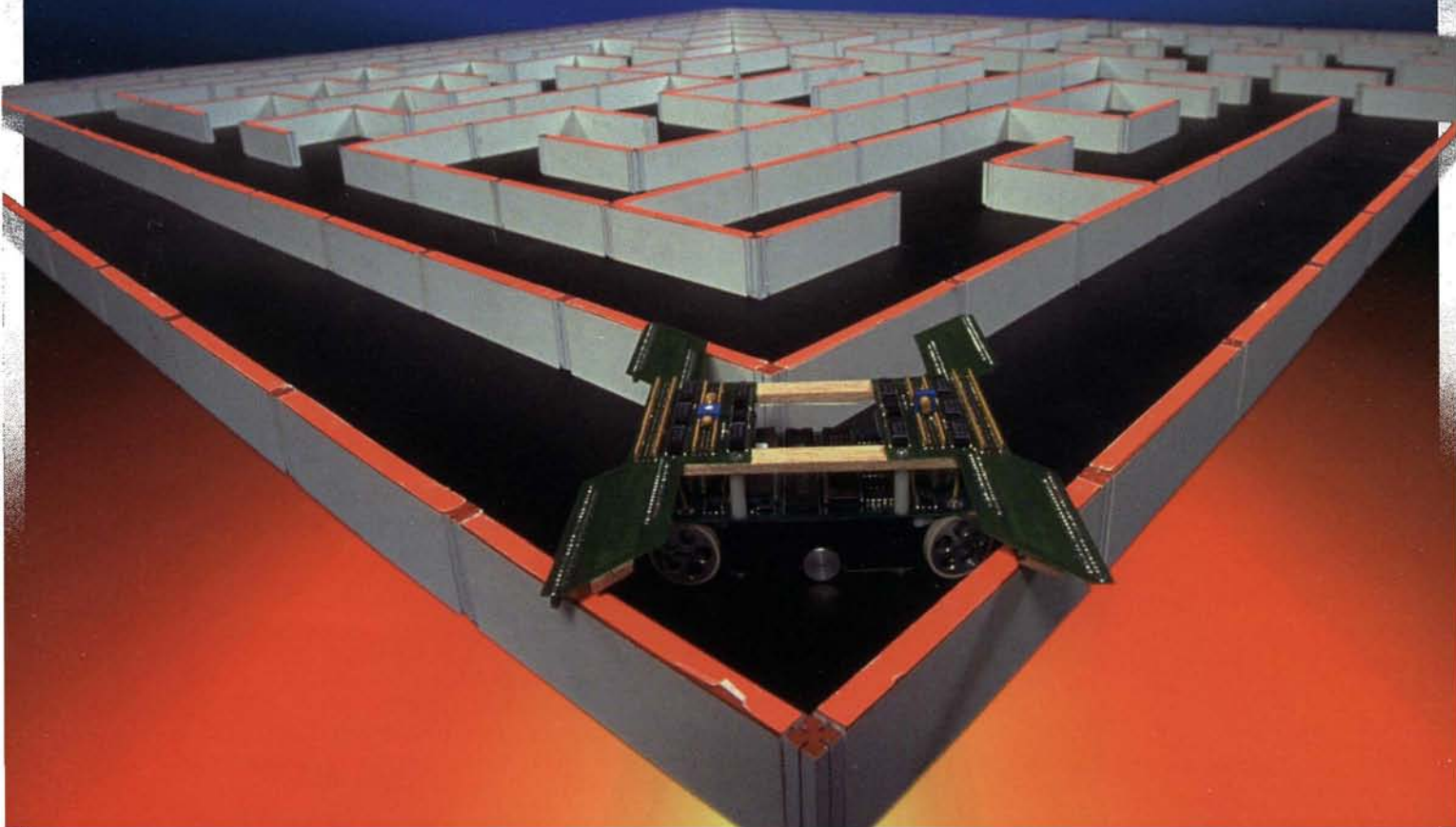
Curiously, like many of the other contestants, Sall and Albretson did not name their robot. "We just never thought about it," Sall told *RS&T*.

RS&T

Popular Micromouse  
Algorithms, Part I

# A Wall Hugging Algorithm

by Tak Auyeung, Ph.D.,  
UC Davis



If A Robot Swims  
Along the Coast of a  
Lake, It will Never  
Reach the Island.

*Photo: "Hugging the wall" shows David Otten's micromouse Mitee Mouse 5 competing in Boston at APEC-92. There are 82 sensors on those wings!*



# Daze

*Yocto* – the smallest and least sophisticated robot in the competition – randomly roamed into the destination cell in one minute, 13 seconds. That was good enough for third prize and \$100.

All in all, only half of the micromice managed to find the destination cell. In the spirit of to-finish-is-to-win, *RS&T* salutes *Ratbert* from the University of the Pacific

(2 minutes, 41 seconds) and *JK4* from UC Davis (4 minutes, 13 seconds) for solving the maze. **RS&T**

*For a more detailed description of the rules and specifications for micromouse competitions, go to:*  
[www.ece.ucdavis.edu/umouse/](http://www.ece.ucdavis.edu/umouse/).

*For more information about IEEE Region 6, go to:*  
[sdcc3.ucsd.edu/~ieee/links/region6.html](http://sdcc3.ucsd.edu/~ieee/links/region6.html)

## The Year of the Wandering Rat

by Tom Durkin

**A**lthough UC Davis' *Knarf* gave 'Iole' *Auana* a run for the money, the micromouse from Hawaii had the winning combination of clever programming, reliable engineering and good luck (i.e., nothing went wrong).

### Lookie Here

According to Tak Auyeung, PhD, a micromouse is comprised of three basic systems: sensor array, power train, and the embedded microprocessor/controller.

"Most micromouse robots can only sense where there is a wall directly ahead, to the left or to the right," said Auyeung, who teaches the Micromouse Design Project at UC Davis.

'Iole' *Auana*, however, used an expanded sensory array that allowed the micromouse to look over the walls and map what was in adjacent corridors, said Tep Dobry, PhD, the faculty advisor for the UH team.

The wide sensor platform utilized 19 paired infrared emitter-receivers. The IR light-emitting diodes were made by Photonic Detectors and cost \$2.40 each. The Panasonic IR receiver phototransistors cost of \$0.44 each, said Dobry. Like most of the parts on 'Iole' *Auana*, the sensors were purchased from Digi-Key Corp.

The front-mounted sensor platform required counterweights – eight large hex nuts – on the rear of the robot to keep it from taking a nosedive, said team member Nathan Mariels.

*continued next page*



You can clearly see the ispLSI Lattice logic chip on the left side of the printed circuit board. Partially obscured by a ribbon cable, the unmarked Motorola MC68020 microprocessor is directly to the right of the Lattice chip. Four DIP switches in a red casing are positioned at the upper right corner of the Lattice chip. To the right of the switches are four green LEDs. Above the LEDs, you can see four of the eight power MOSFETs that drive the stepper motors. Neatly etched in the lower right corner of the motherboard are the words: "Let the smiles win!"

## Wondering Rat, continued

### Digital Drive Train

Mike Masaki and Shigehiro Minami, the hardware specialists on Team 'Iole' Auana, disclosed what made the micromouse run:

The robot was equipped with two 4 Vdc stepper motors manufactured by Eastern Air Devices Inc. They cost \$58 each.

The motors were driven by eight National Semiconductor power MOSFETs (metal-oxide semiconductor field effect transistors) operating at 55 V with 0.74 Rds (resistance between drain and source). The cost from Digi-Key was \$0.94 each.

Six rechargeable Sanyo sub-C NiCds powered the microbot with 1000 mA at 7.2 V. Sub-C batteries are two-thirds the height of standard C batteries and cost about \$4.50 each.

### Brains on Board

The motherboard on 'Iole' Auana was power packed with a 32-bit Motorola MC68020 microprocessor and a Lattice ispLSI 1032-60LJ microcontroller.

Mariels designed the printed-circuit board and had it custom manufactured by Internet PCB Express.

Motorola donated the MC68020 (worth about \$13), and the team purchased the Lattice logic chip from Lattice Semiconductor Corp. for about \$25. The base price for a custom PC board from PCB Express was \$75.

The Lattice chip had 24 sensor inputs, eight outputs for the motors, one serial port, four DIP switch inputs and four LED outputs. Additionally, the Lattice chip performed the RAM/ROM address decoding and timer interrupts, according to Mariels.

One distinct advantage of the ispLSI Lattice chip is that it is field-programmable, meaning that it can be reprogrammed *in situ* through the serial port. This allowed software specialists Nava Zvaig and Mariels to download program changes directly into the 128K onboard RAM. In addition to the RAM, 'Iole' Auana was outfitted with 64K ROM.

Zvaig and Mariels split the formidable task of writing the 4,000 lines of C code. Zvaig concentrated on the maze-solving algorithm, and Mariels took on the tracking program.

### One Smart Mouse Programmer

"This mouse is smart. It always knows where it is in the maze, knows where to go, and it calculates the shortest path between any two

squares in the maze – if such a path exists," Zvaig said.

"For each square the mouse gets to for the first time, I get the reading of seven walls, look at the possible moves from this square and sort them according to their distance from the center. Squares that have been visited already are not considered possible moves," she added.

Except for the programming of the Lattice chip, all the coding was done on Macintosh computers, Zvaig said.

Auyeung said 'Iole' Auana employed "a modified flood-fill algorithm that used a strange tie-breaker strategy when two neighboring maze cells had the same weight."

RS&T

## Component Resources

Digi-Key Corporation

800.344.4539

[www.digikey.com/DigiHome.html](http://www.digikey.com/DigiHome.html)

Motorola MC68020 microprocessor

[www.mot.com/SPS/HPESD/prod/0X0/68020.html](http://www.mot.com/SPS/HPESD/prod/0X0/68020.html)

Photonic Detectors

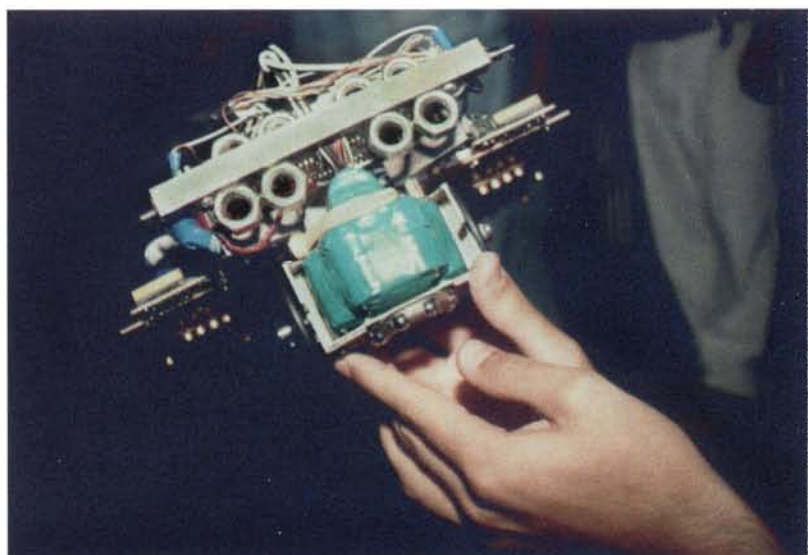
[www.mcdelectronics.com/photonic.htm](http://www.mcdelectronics.com/photonic.htm)

Eastern Air Devices Inc.

[www.eadmotors.com/](http://www.eadmotors.com/)

Internet PCB Express

[www.pcbexpress.com](http://www.pcbexpress.com)



From the rear of 'Iole' Auana, you can clearly see the green Sanyo battery pack and some of the hex nuts used as counterweights to keep the micromouse from tipping forward.

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- Complies with ETS 300-220 regulations
- 40kbit/s half duplex
- Free format packets of 1-27 bytes
- Packet framing and error checking are user transparent
- Collision avoidance (listen before transmit)
- Direct interface to 5V CMOS logic
- Single 5V supply @ < 20mA
- Power save mode
- Available in 418 and 433 Mhz



The **BiM module** integrates a low power UHF FM transmitter and matching superhet receiver with data recovery and TX/RX change over circuits to provide a low cost solution to implementing a bi-directional short range radio data link.

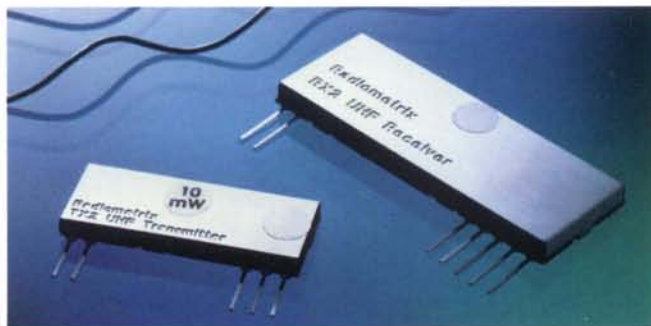
- ETS 300-220 tested for European use
- SAW-controlled FM transmission at -6dBm ERP
- Double conversion superhet receiver
- 107dBm receive sensitivity
- Single 4.5 to 5.5V supply < 15mA (tx or rx)
- Reliable 30m in-building range
- Half duplex data at up to 40kbit/s
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- On-Board data slicer, supply switched and antenna change over
- Available in 418 and 433 Mhz



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- Transmitter - TX2
- EMC conformant to ETS 300-683
- Type Approved to ETX 300-220
- Two-stage, SAW controlled, FM modulated at up to 40kbit/s
- Operation from 2.2 to 6V
- 10mW on 433.92MHz, 1mW on 418MHz
- Improved frequency and deviation accuracy
- Available in 418 and 433 Mhz

- Receiver - RX2
- Double conversion FM superhet
- SAW front end filter, image rejection 50dB
- Supply 3.0 to 6.0V @ 13mA
- 40kbit/s, -F version, -100dBm sensitivity @ 1 ppm BER
- 14kbit/s, -A version, -107dBm sensitivity @ 1 ppm BER
- LO leakage < -60dBm
- Available in 418 and 433 Mhz



## TYPICAL APPLICATIONS

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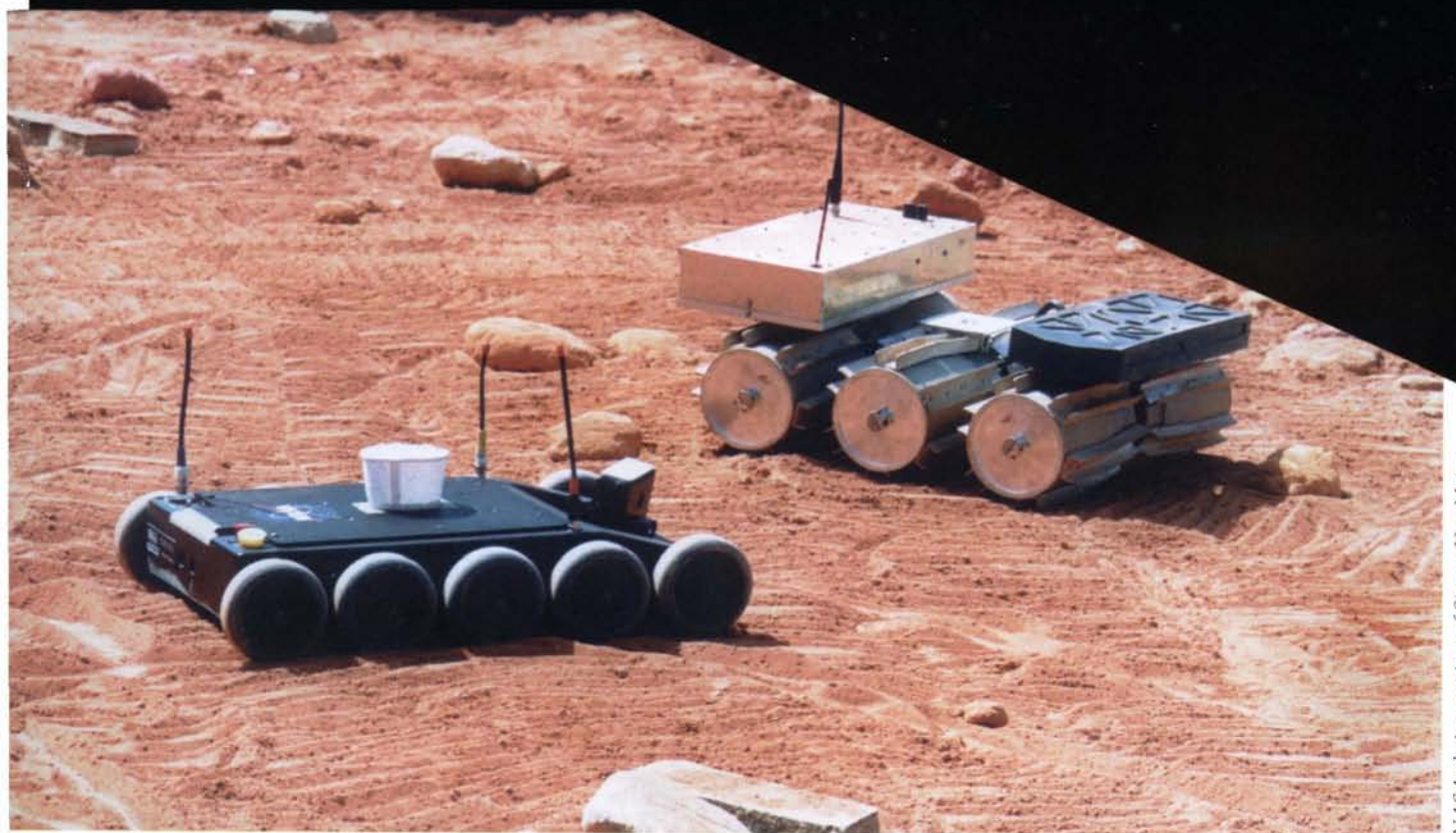
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# Space



NASA photos courtesy of Steven Van Meter.

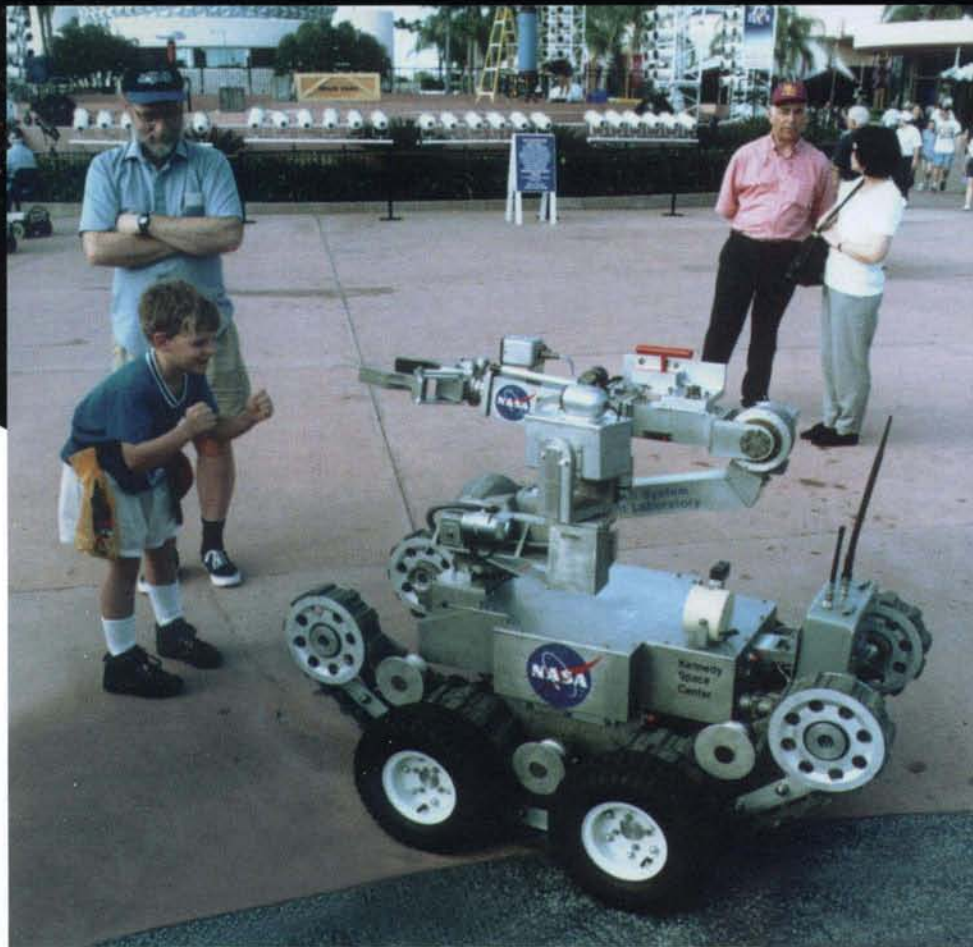
Above, in a Mars Yard at EPCOT, ISE shows off its six-wheeled rover. Approaching it is NASA's ten-wheeled flightline vehicle, used for making deliveries to Andros "where no human dares to tread."



Photo courtesy of International Space Enterprises.

Upon landing, a space shuttle's tires may become dangerously hot enough to explode. So who would walk up to let the air out? Not me! NASA's hazardous duty robotic specialist Steven Van Meter says that's a job for Andros (facing page). This particular Andros is one of many in a line of hazardous material handling bots. The controller watches video feed from either a chassis-mounted camera or a camera on the

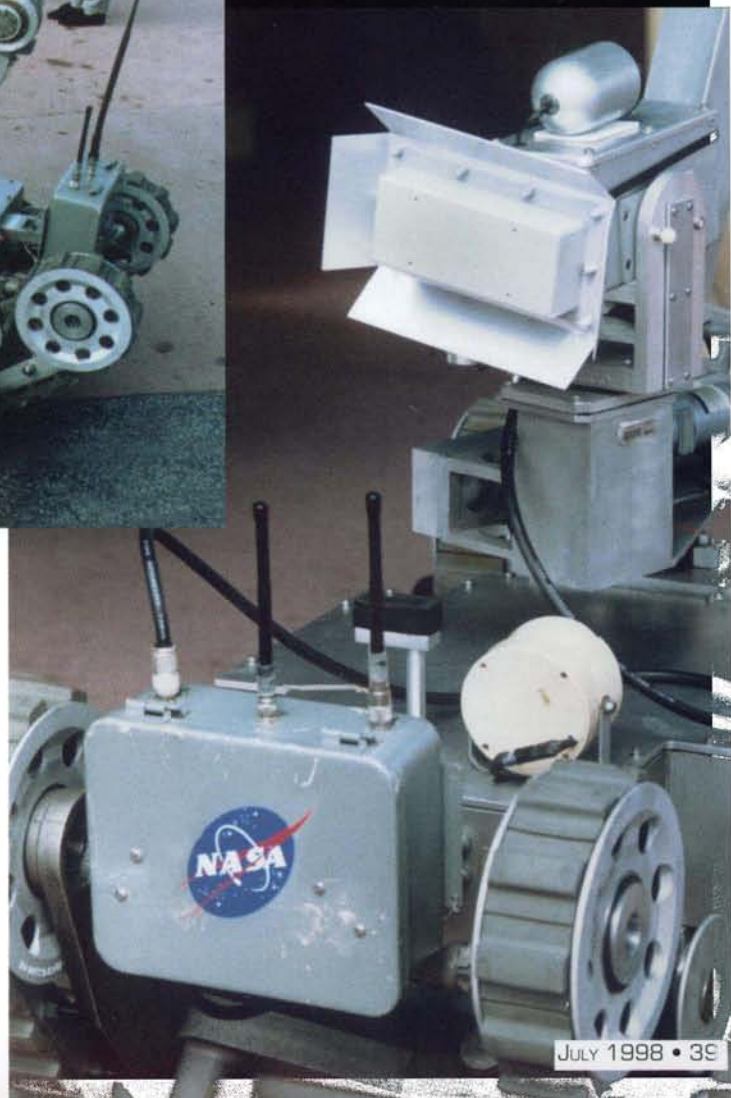
# Jam



Disney's EPCOT hosted a Science Celebration, including the Space Jam where we found NASA and IS (International Space Enterprise) showing off some of their wares. Left: a modified radio-controlled ANDROS Mark V approaches a young admirer.

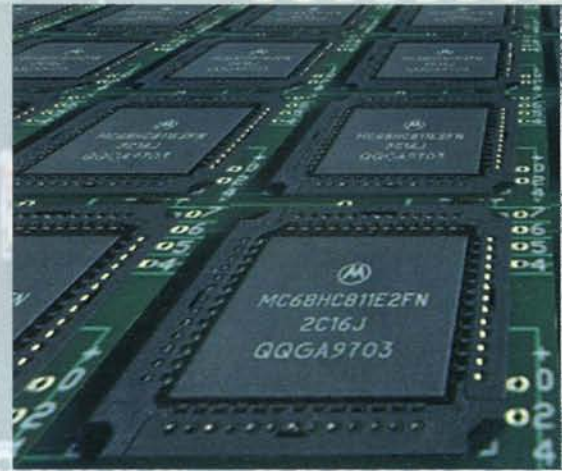
gripper arm, and sends control signals by either radio link (photo, right) or cable. This Andros has wheels placed alongside the articulated tracks, to improve performance on NASA's flightline at Kennedy Space Center. The Andros line (made by Remotec) is one of the world's most popular hazardous materials handling robots (especially used by police and military bomb squads). For more on the articulated tracks and Andros' work with bombs, see RS&T's Online Supplement at [www.RobotMag.com](http://www.RobotMag.com).

RS&T



# Basics of a Digital Brain:

## Part 2



by veteran robot programmer Karl Lunt,  
Seattle Robotics Society

Last month, I got you started on using the 68HC811e2 as the brain for your first robot. By now, you should have your BOTBoard up and running, and maybe even done some dabbling in SBasic. If you don't have SBasic yet, stop by my web site at [www.seanet.com/~karllunt](http://www.seanet.com/~karllunt) and get a copy from my tips and techniques page. This month I'll describe how to program the 68HC11 as a robot brain.

### More I/O

The 68HC11 variants usually support eight channels of 8-bit A/D. This means that any of eight pins, usually appearing on port E (PORTE), can translate an analog voltage into a digital number from 0 to 255. This little feature is way cool for robotics, since much of what a robot has to detect is analog, rather than digital, in nature.

One of the simplest features to install in a robot is that of light-sensitivity. Suppose your robot is equipped with solar panels for recharging an on-board battery. Obviously, you would want your robot to find a patch of sunlight on its own, then sit and soak up the rays during lunch. This means that your robot must somehow sense the sunlight and deduce the direction to that sunlight so it can steer itself properly. The sensing part of the equation requires a light sensor, such as a photocell, and some means of determining the resistance or voltage returned by that photocell. And reading voltages is what the A/D ports do best.

I've included here a small SBasic program called ADTEST.BAS as an example of how to use several important features of the 68HC11. Besides

demonstrating a technique for reading the A/D ports, it also shows you how to use the real-time interrupt to set up a simple timer variable, and how to set up and use the 68HC11 serial port for use with SBasic's PRINT statements. I'll walk through the program with you, focusing on how to use the A/D ports.

As with all SBasic programs, the 68HC11 begins executing your program at the label MAIN, which appears here immediately after the INTERRUPT code. As mentioned in the SBasic user's manual, the label MAIN can appear just about anywhere in your program, but it must appear somewhere; otherwise, the MCU doesn't know where to begin execution.

The code at MAIN does a few different tasks, including setup of the serial port. The line of code we're interested in uses the POKEB command to modify the OPTION register. By forcing bit 7 of OPTION to a 1, this statement turns on the 68HC11 A/D subsystem so the internal A/D converters will actually read a voltage when requested. Refer to the 68HC11 Reference Manual ("the pink book") for details on setting up the A/D subsystem. (Ask Motorola for a free copy of M68HC11RM/AD Rev 3 by calling 800.441.2447).

Following the A/D setup, the code at MAIN falls into an infinite DO-LOOP structure that checks the value in a countdown timer named WAIT. Whenever WAIT becomes 0, code in MAIN resets WAIT to a new value, then calls the subroutine READ\_JOYSTICK to read and report voltages on all eight A/D ports. This sequence of waiting, then reading, continues until you turn off power to the 68HC11.

The code that actually reads an A/D port resides in READ\_JOYSTICK. Note the two lines in this routine that write a byte to the address ADCTL. The first such line writes a \$10 to ADCTL, which causes the 68HC11 to read A/D channels 0 through 3, storing the results in four I/O registers named ADR1 through ADR4. The second such line writes a \$14 to ADCTL, which places the values from A/D channels 4 through 7 in those same registers. Note that the 68HC11 takes a little bit of time to read the registers, so I've included a short FOR-NEXT loop after each change to ADCTL.

When you run the program, you'll see a set of eight hexadecimal values appear on your terminal screen about twice per second. If you change the voltage connected to one of the PORTE pins, the corresponding value will vary accordingly.

So what kind of voltage can you apply to a 68HC11 A/D input? The 68HC11 includes two pins dedicated to the A/D subsystem, named Vrl and Vrh. Whatever voltage appears between these two pins serves as the reference voltage for the A/D subsystem. Normally, these pins are connected to ground and +5 Vdc, respectively, which means that any analog voltage applied to an A/D input must stay within those limits.

Back to our example of sensing light levels. You can hook a cadmium-sulphide (CdS) photocell to an A/D port and make a simple

## ADTEST.BAS

```
include "regs11.lib"

declare wait
declare n

interrupt $fff0           ' RTI service routine
if wait <> 0              ' if timer variable not 0...
    wait = wait - 1      ' decrement it
endif
pokeb tflg2, %01000000   ' always rearm RTI interrupt
end

main:
pokeb baud, $30           ' 9600 baud
pokeb sccr2, $0c         ' turn on rcvr and xmtr

print
print "ADTEST - sample A/D ports and display values in hex"
print
print

pokeb tflg2, %01000000
pokeb tmsk2, %01000000
pokeb option, peekb(option) or $80 ' turn on A/D system

wait = 0
interrupts on            ' allow interrupts

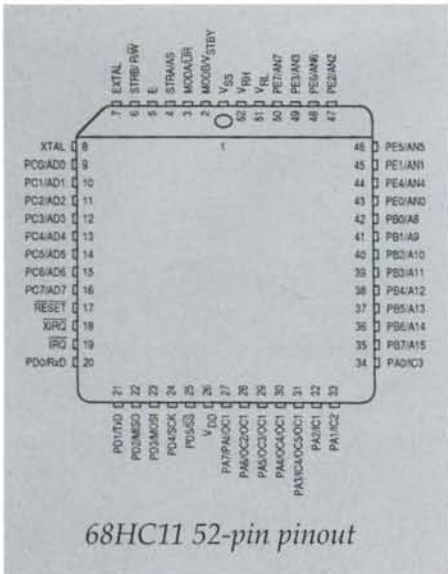
do
    if wait = 0          ' time to read?
        wait = 125      ' yes, reset timer
        gosub read_joystick ' read and report
    endif
loop                    ' do forever

'
' read_joystick          read the eight A/D ports
'

read_joystick:
pokeb adctl, $10        ' convert chnls 0-3
for n = 0 to 10         ' wait a bit
next
outch $0d               ' make it pretty
printx "Values: ";     ' do a heading
printx " "; peekb(adr1);
printx " "; peekb(adr2);
printx " "; peekb(adr3);
printx " "; peekb(adr4);
pokeb adctl, $14        ' convert chnls 4-7
for n = 0 to 10         ' wait a bit
next
printx " "; peekb(adr1);
printx " "; peekb(adr2);
printx " "; peekb(adr3);
printx " "; peekb(adr4);

return

end
```



light-level sensor. Stop by a Radio Shack and pick up a suitable photocell and a 10 k resistor. Wire one end of the photocell to one end of the resistor. Now hook the free end of the photocell to the positive power terminal on your BOTBoard, the free end of the resistor to the ground terminal, and the

junction of the two devices to the first A/D input, PE0. Run your program again and notice the effect on the values displayed for channel 0 as you move the photocell around.

As you can see, the A/D port returns considerably different values, depending on the light that strikes the photocell. But one photocell is only enough to tell you the light level in general. To provide steering information, hook a second photocell and resistor combination to PE1. If you mount these photocells on your robot frame so each cell is pointing in a different

# Basics of a

direction, your robot will be able to "see" different light levels and decide which direction to steer.

Now you just need to write some robot code that reads both photocells, then turns toward the brighter light until both light levels are equal. Once both light levels balance, the robot can go forward. Finally, when both light levels balance *and* the levels are above a required minimum, the robot can simply sit in place, soaking up the sun.

## Getting digital

Most robots need to know when they've bumped into a wall or other obstacle. Electronically, this bumper switch is just a resistor wired between +5 Vdc and an input line, with a switch between that input line and ground. The resistor, called a "pull-up" because it pulls an input line up to a voltage, ensures that the input line sees a logical 1. When the switch closes, however, the input line is forced to ground and sees a logical 0. By reading the port attached to that input line, your software can examine the associated bit and deduce the state of the bumper switch.

For the 68HC11, you will normally use an I/O line on PORTC for bumper switches. Remember that anytime your software uses PORTC, it must first define

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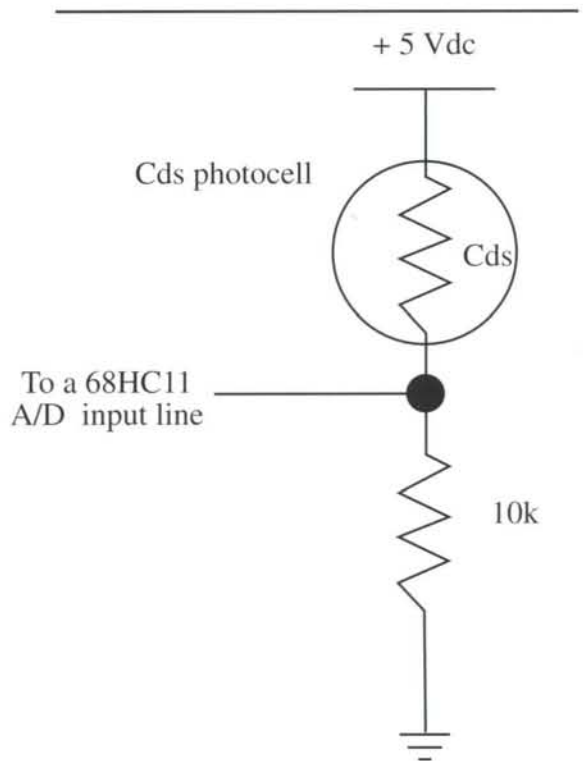
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Adding a light sensor



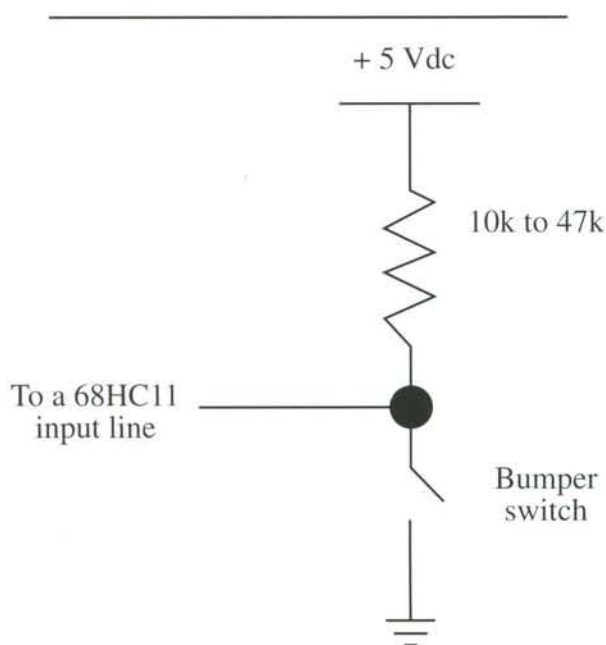
# Digital Brain

the direction of the PORTC lines by writing a setup value to DDRC.

Port C (PORTC, address \$1003) works almost exactly like PORTB, but you can declare some of the port C lines as digital inputs and some as digital outputs. This declaration takes place using an I/O register named DDRC (address \$1007). Before your program tries to use PORTC, it should first declare the directions of all PORTC lines, so you don't inadvertently change some external circuit. The value your program writes to DDRC determines the direction of each PORTC digital line. Writing a 0 to a bit in DDRC makes the matching bit in PORTC an input line; writing a 1 to a bit in DDRC makes that line an output instead.

Once you've set up DDRC, your program can change the state of the PORTC output lines by writing a value to PORTC, just as I've described for PORTB above. Any PORTC lines that have been configured as digital inputs will ignore the change; those lines remain inputs to the outside world. Similarly, your program can read PORTC to determine the current state of those pins configured as inputs. When your program reads a PORTC input line, the corresponding bit will be 1 if that line is connected to 5 Vdc or 0 if that line is connected to ground. Reading any output pins will return the value most recently written to them.

Note that the "bumper switch" actually can be almost any mechanical device that closes a circuit.



Adding a bumper switch

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## Accessories

<b>STA-01</b>	Counterfeit BASIC Stamp Kit . . . . .	<b>\$40.00</b>
<b>SSC-01</b>	Mini SSC II Servo Controller . . . . .	<b>\$44.00</b>
<b>IRPD-01</b>	IR Proximity Detector Kit . . . . .	<b>\$30.00</b>
<b>TRA-01</b>	Tracker Line Tracking Kit . . . . .	<b>\$20.00</b>
<b>S1-01</b>	Hitec 42oz/in Single Servo . . . . .	<b>\$15.00</b>
<b>S6P-01</b>	Hitec 42oz/in Servo 6 Pack . . . . .	<b>\$80.00</b>
<b>SLS-01</b>	Hitec 133oz/in Large Scale Servo . . . . .	<b>\$40.00</b>
<b>BMR-01</b>	Mobile Robots Book . . . . .	<b>\$48.00</b>
<b>BP-01</b>	PVC 8x12x1/8" Blank Panel 3 Pack . . . . .	<b>\$10.00</b>

## Ordering

S&H; add \$7.50 for a single robot kit and IRPD / Tracker sensor. Add \$3.00 for each additional robot kit or book. Call, fax or e-mail for quote for international or large orders. IL Res. add 6.25% sales tax to total.

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# Basics of a Digital Brain

The most common form of bumper switches are made from microswitches, available at mail-order outfits and larger electronics stores. About one inch square and made from hard plastic, these switches have a long, thin metal leaf that trips the switch inside when the leaf is pressed against the switch. You can mount such a switch to the body of your robot, then fasten a plastic or metal skirt in contact with the leaf. Your robot can now sense when an obstacle touches the skirt because the pressure will force the leaf to the closed position.

You can adapt other mechanical techniques of switch closures to your robot designs. For example, you can remove individual keys from a surplus keyboard, then use the scrap keys as fingertips or gripper switches, so your robot knows when it has grasped an object. I've seen tilt-switches for sale in some of the mail-order catalogs, suitable for helping your robot realize it has tilted or fallen over. And Mark Tilden, of BEAM robotics fame, has crafted some truly wonderful whisker sensors out of fine brass springs and wire-wrap posts. For details on these whiskers, browse the Solarbotics web site at [www.solarbotics.com](http://www.solarbotics.com).

If you get stuck, or if you want to share some thoughts on robotics, you can reach me at: [karllunt@seanet.com](mailto:karllunt@seanet.com). Good luck with your first project, and welcome to a fascinating world.

RS&T

## KARL'S SUGGESTED RESOURCES

### Single- and Multiple-Chip Microcomputer Interfacing

by G. J. Lipovski

(Prentice-Hall, Inc., ISBN 0-13-810557-X)

The electronics are actually quite simple, and building a working system from scratch will make you that much better of a robot builder.

Buy the blank BotBoard from Mondotronics ([www.robotstore.com](http://www.robotstore.com)) for about \$10.

You will also need to find and order the remaining parts, including the 68HC811e2 MCU device and a matching 52-pin PLCC socket. The BotBoard documentation includes a full parts list with suggested suppliers. Expect to spend about \$50 in all to build up your first BotBoard.

Find a copy of pbug11 at

[www.mcu.motps.com:80/freeweb/](http://www.mcu.motps.com:80/freeweb/).

Follow the links that take you to the 68HC11 area. Download the program pbug342.exe, copy it to a new directory called pbug11), and execute the program. It will expand into a working version of pbug11 with all of its necessary support files.

You'll need an assembler and a compiler to create code for the 68HC11.

I suggest you stop by my web site at [www.seanet.com/~karllunt](http://www.seanet.com/~karllunt) and hit the Tips and Techniques page. There you will find a copy of my SBasic distribution file; this file contains the SBasic compiler and a serviceable assembler, plus a lot of sample programs. You will also find a link to a page explaining in detail how to use pbug11 to talk to a BotBoard. Download that page and file it away for reference.

You absolutely *must* have Motorola's *M68HC11 Reference Manual (M68HC11RM/AD)*.

Call 800.441.2447

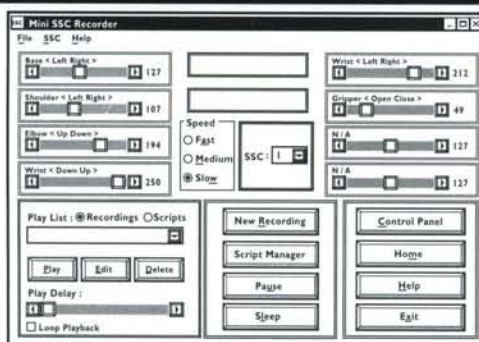
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# Feedback Loop

"Roboticians have to be the most skilled generalists. Their discipline requires that they have skills in every area of expertise. So they need to read every book they can get their hands on."  
— Scott Edwards, page 51

Two thumbs up (one flesh, the other metal) for Robot Science and Technology. Keep 'em coming..I will definitely be a steady subscriber... I appreciate the unique combination of coverage of what's going on in academia and the real world combined with reportage of amateur robotics events and tips and tutorials for us independent experimenters. I even appreciated the centerfold...:-) That's how I knew this magazine was produced by kindred spirits...  
*Rayden Tron*

WOW! I've only read up to page 21, and I am so jazzed that I had to write before I finish the rest of the mag.

I wanted to say a whole lot more, but I'm just too anxious to get back to the mag. So far it has been very motivational and educational. Keep up the good work!  
*Montgomery Tidwell*

I not only enjoyed but also understood the first articles I read. I've always dreamed of being involved in robotics and your magazine is making the itch stronger. This issue made me feel I that I can do it. Thanks.

*Wendy Bradley,  
Nottingham Trent University*

In your first issue, I found many of the articles separated by too many pages. Also, I would really enjoy a more in-depth article on construction, problems, and other things about the 'Big Blue' LIS robot. I really enjoyed your magazine and want you to know you've got a life-time subscriber.

*Quincy Styke IV*

*Good points, Quincy. We split articles with "jumps" because some longer articles had full color photos, and others didn't need color. We hope to keep improving with age, to give reader's what they want. For instance, I think you'll like this month's centerfold, Big Blue.*

I wonder if I will one day be telling my kids, "Back in my day, we had to build our robots." Much like the day of building your own computer, just a couple decades ago.  
*Brian Bernacki*

I especially liked The Iconoclast's "Home Robots—NOT!", and the details of the fire-fighting robots. Thanks for rushing a replacement magazine to me when mine was lost.  
*Mike Baron*

I've been looking for this kind of information for a long time. My background is as a mechanical engineer and programmer but I don't know anything about electronics. I don't know a resistor from a lug nut.

Also, I'd like to see reviews of kits. In most kits, the instructions don't teach you anything more than "put resistor A into holes H1 and H2 and solder." I want to know how the circuits work so I can modify them or create my own.

I'd also like more articles like your F.E.A.R. article in the Premier Issue. Maybe a multi-part article that shows precisely how to build a small robot from start to finish. Maybe you could even sell a parts kit.  
*Mike Glass*

Congratulations on a well-designed magazine in a much-needed field. Embedded systems periodicals have been trying to cover the gamut from single-chip solutions to embedded PCs and failed at both ends. It's nice to see someone carve out a niche and excel.

In the Pathfinder article, Mr. Reeves makes one exceedingly important point, "We strongly believe in the test-what-you-fly and fly-what-you-test philosophy." That singular statement should be nailed to every programmers monitor in 18-point type. Ironically, the failure in the Mars Lander was precisely because this philosophy was not followed. The conditions under which the Lander was tested were violated when "the data thread was not enabled in Pathfinder's VxWorks."  
*Albert Lee Mitchell*

**WE'D LOVE TO READ YOUR  
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## First Step from Lynxmotion

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Programming the First Step is easy. Simply plug the modular connector from the PC's parallel port into the micro's modular adaptor. Run the Parallax program STAMPEXE and load one of the many sample BASIC programs into the editor. Apply power to the First Step and press Alt-R. (The program is downloaded to the micro, and automatically begins running.)

To make changes, just edit the code and press Alt-R. The micro stops, accepts the new code and starts running the new code.



The programming cable may be removed at any time for complete autonomous operation. The code is stored in an EEPROM, and therefore is protected from power loss.

Lynxmotion also sells many affordable driver and sensor accessories for the First Stamp controller. These devices feature the same 1.3" x 1.5" footprint, high quality double sided boards with the same ground plane, solder mask and parts placement guide as the First Step:

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- The Dual H-bridge (DC Motor Driver) lets the micro to control the speed and direction of two DC motors for use in drive systems.





### **First Step Specs:**

**CPU Power Requirements**—6 to 15 VDC at 2 mA not including I/O needs. Alternately a regulated 4.5 to 5.5 VDC may be applied to the +5V in / out pin.

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Price: First Step Kit, FS-01—\$40.00  
Programming Cable, DB25-01—\$6.00

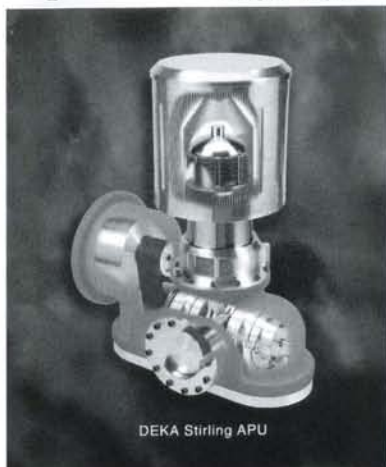
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DEKA Stirling APU

# Resource

Many readers referred us to Small Parts Inc as a source for, of course, small parts. I already knew that robot warriors relied on them, and I personally rely on their catalog for information. It's not just a list of stuff, it's educational, too. Best of all, they can ship small quantities. (And they are *not* surplus.) They also have a machine shop to take your special orders.

In their 448-page catalog, you'll find small and miniature tools, laboratory equipment, hardware, bearings, drive and fluid control components, fasteners, and diverse sizes and shapes of materials like plastics, rubbers, nylon, Teflon, steel, aluminum, brass, bronze and copper... Enough said?

We found that Small Parts Inc actively supports robot builders. In fact, as an avid supporter of the FIRST competition series, SPI supplies *a lot* of free materials to the robot-building teams. This promotes equity between the small teams and the teams with big corporate sponsors. They also sponsor the Woodie Flowers Award to celebrate effective communication in the art and science of engineering and design.

Get their illustrated 1998 catalog by calling 800.220.4242 or emailing [smlparts@smallparts.com](mailto:smlparts@smallparts.com).

Find more info on the FIRST robotics competition at 800.871.8326 or [www.usfirst.org](http://www.usfirst.org). —Mike

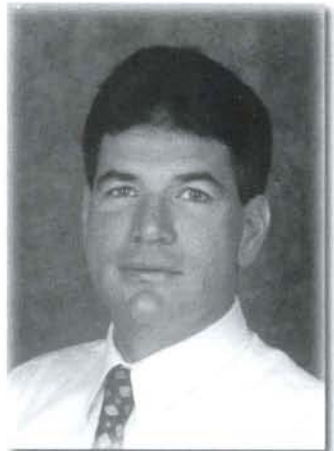


## IRIS GILBERT

GRAPHIC ARTIST

We at RS&T are fortunate to add graphic artist Iris Gilbert to our team here in Rocklin. Her photography and computer graphics skills clarify and beautify many of the images in this issue. In fact, check out this month's cover, "Hugging the Wall."

We're looking forward to seeing plenty more of her photographs and computer magic gracing the covers, centerfolds and illustrations of many future issues.



## BOB BRADY, PH.D.

MIT LINCOLN LABS

A certified bell-ringin' monk at one of America's cathedrals of science, Dr. Bob Brady has a talent for clear narrative to add to his B.S. in mechanics, M.S. in alternative energy and Ph.D. in machine vision. "I feel very strongly about making science and modern technology accessible to the average person."

Bob integrates science and math into the construction details of the popular *TuteBot* design on page 6.



## TAK AUYEUNG, PH.D.

UNIVERSITY OF CALIFORNIA AT DAVIS

We met Tak Auyeung at the IEEE Region 6 micromouse competition (page 34) at UCD, where Tak teaches the UCD Micromouse Lab. In his other life, he's the software development group leader for embedded controllers at Zworld. RS&T is happy to present the first of his series of maze solving algorithms on page 30.

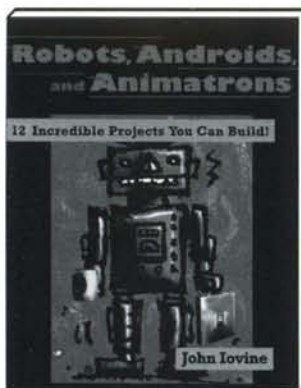


## RICK HAHN

FABRICATION ARTIST

It took an artist to do what couldn't be done. Plastics manufacturers told RS&T that injection molding small parts was beyond the abilities of home experimenters. But artist Rick Hahn proved them wrong. Follow Rick's step-by-step instructions (starting on page 16) to learn how to duplicate small, complex parts in plastic using inexpensive homemade injection-molds and some patience.

# resources



## Robots, Androids, and Animatrons: 12 Incredible Projects You Can Build by John Iovine

With this wonderful book, science and electronics experimenter John Iovine gives us the penultimate "First Reader" of robotics. This fast-paced and easy-reading survey of real-world and hobby robotics overviews a dozen different kinds of robot technologies. It has a good introduction to the thorny discussions of artificial life, intelligence and consciousness. In most of this book, Iovine challenges the reader with hands-on projects that explore power and locomotion (such as solar, battery, air muscle, nitinol, servos and stepper motors), sensors (light, IR, speech, ultrasonics, pressure and more), Basic Stamp microcontrollers, BEAM, telepresence, simple mobile kits, walkers, underwater and airborne robots. After helping us all these projects, Iovine guides us through building an android hand using air muscles, a BASIC program and a toy arm. Full of clear photos, schematics and diagrams. Completely indexed. Includes sources for parts.

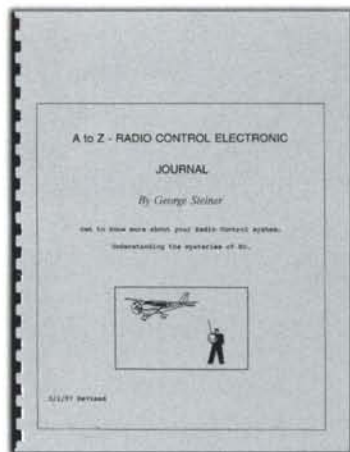
Found at major bookstores, [www.amazon.com](http://www.amazon.com) or [www.tabelectronics.com](http://www.tabelectronics.com), Tab Books, ISBN 0-07-032804-8, 270pp, pback, \$19.95

## A to Z - Radio Control Electronic Journal

revised 1997 by George Steiner

A renowned radio control veteran shares his extensive knowledge and experience in this RC receiver and transmitter tutorial, with emphasis on RC model aircraft. He provides personal notes, drawings and charts illustrating the basics of AM, FM, PPM, and PCM equipment in this handy, fact packed journal. Here are details in major fields of knowledge including: channels, frequencies, antennas and radiation patterns; battery backups and charging systems including load testing; servo resolution, testing, modification and reversing. There are over a dozen simple electronic building projects and a list of handy phone numbers for buying or servicing RC equipment, supplies and test equipment. This profusely illustrated book is a good start for getting a hands-on understanding of radio control, 132pp soft cover.

Send check or money order for \$19.95 to GSP AZ Journal, 2238 Rogue River Dr, Sacramento, CA 95826, 916.362.1962.



## The Prop Builder's Molding & Casting Handbook

by Thurston James

UCLA's theater properties master Thurston James easily details molding and casting procedures for builders of every level of proficiency, using over thirty different materials from papier-mâché and plaster to polyester resin, rubber latex, neoprene, silicone and the urethanes. Novices will appreciate the conversational "How to Get Started" attitude; and journeymen will enjoy the challenge and reward of making a vacuum forming machine. The author focuses on theater props such as masks, breakaway bottles and fake fish. However, robot builders who need to make custom chases will find this resource invaluable. Glossary, source list, index and 450 step-by-step photos.

Available at: F&W Publications, Inc, 800.289.0963, and at plastics suppliers

Betterway Books, ISBN 1-55870-128-1, 236pp, pback, \$19.95

# FEED YOUR HEAD

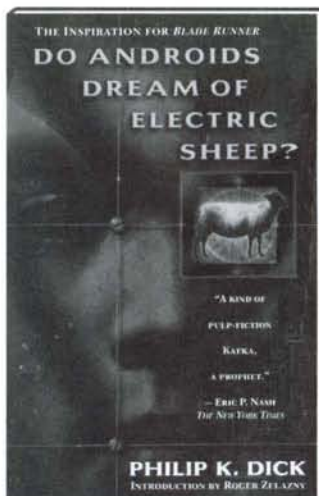
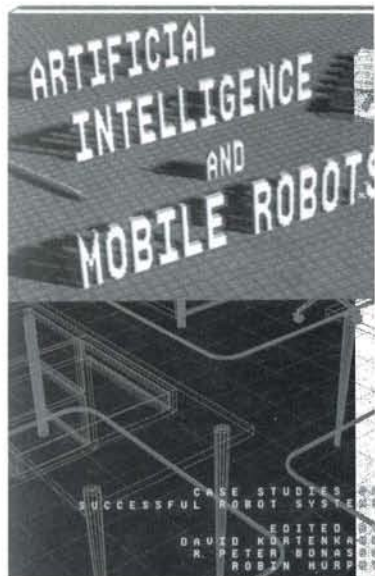
## Artificial Intelligence and Mobile Robots

edited by David Kortenkamp,

R. Peter Bonasso & Robin Murphy

"Real systems are judged by performance, not by papers," seems to be the philosophy of the authors and editors. Here are thirteen case studies of autonomous mobile robots from leading researchers and universities. All have succeeded outside the lab, most are distinguished competition winners, and some are well-known names like Rhino, Carmel, Dervish, Xavier and Phoenix. Major topics include control architectures, real-time navigation algorithms, map learning, vision, and action-oriented perception. College-level reading. Some chapters assume knowledge of probability functions. Well-indexed and illustrated with diagrams, pseudo-code, photos, screen shots, and an extensive bibliography.

AAAI Press/MIT Press, ISBN 0-262-61137-6, 390pp, pback, \$37.50.  
Found at major bookstores or order from MIT Press, 800.356.0343,  
mitpressorders@mit.edu



## Do Androids Dream of Electric Sheep?

by Philip K. Dick

Here's the sci-fi masterpiece that spawned *Blade Runner*. This book is not simply better than the movie: If you liked the movie's special effects, then this book is twice as good as the movie. If you liked *Blade Runner's* plot twists and bizarre way of asking serious questions about consciousness, humanity, and an android's right to life, then this book is a *hundred* times better than the movie. In short: a bounty hunter is tasked to 'retire' artificial humans who are escaping their Martian slavery on a post-apocalyptic Earth, where they are outlawed.

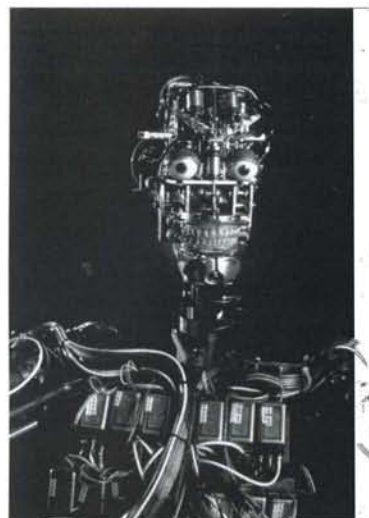
Del Rey, ISBN 0-345-40447-5, 244pp, pback, \$11.95  
Found at major bookstores.

## Robots Rising

Produced by Arcwelder Films

Want a non-technical crash course in the state of the art of robotics? Check out Discovery Channel's *Robots Rising*. Narrated by Linda Hamilton, who starred in the *Terminator* movies, this informative and fascinating video explores both the applications and implications of robots in modern society. From robots as toys to robots as tools, *Robots Rising* features an amazing variety of machines that can amuse us, mimic us – and even replace us. Some of the showcased robots include the bomb-handling *Andros 5*, the interactive *Baby Doll* from MIT, Honda's life-size humanoid, the insect-like *Walkman*, and the truly untouchable *Rosie* that handles nuclear waste. The program includes interviews with some of the world's top roboticists – Rodney Brooks of MIT's AI Lab, William "Red" Whittaker of Carnegie Mellon University, Mark Tilden of the Los Alamos National Laboratory, and Shigeo Hirose of the Tokyo Institute of Technology.

Produced by Arcwelder Films, *Robots Rising* aired on Discovery Channel in March. The two-hour videotape is available for \$19.95 by calling 888.404.5969.





# Programming and Customizing the BASIC Stamp Computer

by Scott Edwards, Scott Edwards Electronics, Inc.,  
[www.seetron.com](http://www.seetron.com)

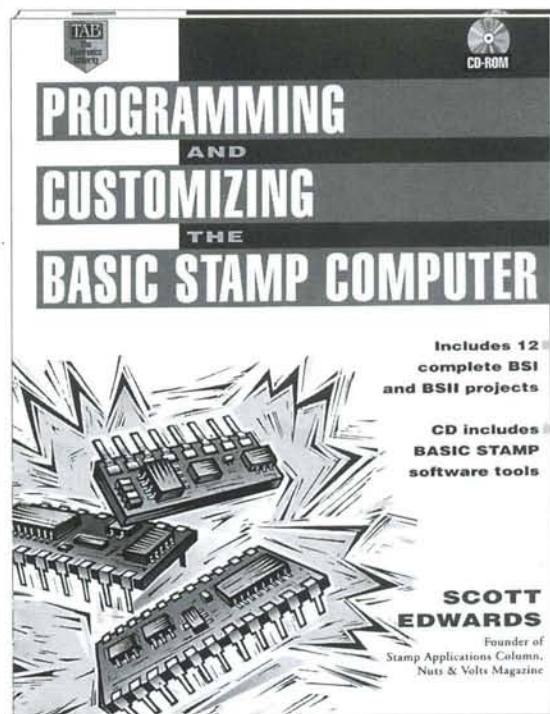
"This book will show you how to get started building fantastic projects with the Stamps." These are true words. Scott Edwards is perhaps the foremost writer on the BASIC Stamp microcontroller, and this book is a comprehensive and authoritative tutorial on the easy-to-use Parallax BASIC Stamp.

Long-time readers of Scott's columns will recognize the easy-reading and technically complete tutorial. This book assumes no special prior knowledge, and offers the practical side of a college education in microcontroller programming. It's profusely illustrated and full of *complete* code listings.

What's a microcontroller? And how does it differ from a microcomputer? What does a BASIC program look like? Read chapter 1. What's a Stamp? An interpreter? A PIC? Read chapter 2. Scott starts with the simplest questions for beginners and builds expertly on that knowledge to build your programming skills.

In plain English, chapters 3 and 4 give us a customized introduction to electricity, discrete components, prototyping and soldering that is written especially with the new Stamp robot builder in mind. In this one book is all the information you'll need to move up to Stamp programming.

Can't remember your programming classes from school? No problem. Scott provides a BASIC Stamp Boot Camp, with 12 complete projects, 6 appendices



including clear explanations of computer math, Boolean logic, Ohm's Law, digital switches, RC timing and much more.

Something that roboticists should note: While Scott's applications have not concentrated on robotics (there are plenty of other uses for Stamps), *every one* of the projects in this book can be instantly applied to robotics sensors, data logging or communication.

As a great added value, Scott has included a CD with *three years* of his magazine columns. The CD also contains the *entire* Parallax BASIC Stamps manual with all the manufacturer's applications notes (450 pages) and all the software tools you'll need to program Stamps on your DOS machine.

Since most of the documentation on the disk is in the Adobe Acrobat format, a copy of the free Acrobat Reader software is included for Win 3.x, Win95, NT, Mac and Unix.

*Programming and Customizing the BASIC Stamp Computer* is a quality publication from TAB Books ([www.tabelectronics.com](http://www.tabelectronics.com)). ISBN 0-07-93684-2, softcover, \$34.95. **RS&T**

*In a special offer from Parallax Inc., Robot Science & Technology readers can get the book, a BASIC Stamp Rev D, and a programming cable for your PC, at a special package price of \$59 (a 40% discount).*

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# Booting Up Your Small Robotics Business

*Neither Sleet nor Snow nor...Huh???*

*PropTop learns the hard way: what you don't know about the mail can kill you. You'll commit SUICIDE!*

## **Can't you just drop your mail in the box? Yes, but...**

**O**nce upon a time, in a neighborhood very near your house, a really smart propeller-head had a Bright Idea for a business. IntelliHonkers.

He knew everything he needed to know about his product. And he felt he was pretty smart about business. His confident personality would surely lead to sales. So he decided to mail out some fliers and sit back while the money poured in.

Why waste time? A nearby printer would make his flier. The printer told him that sorted bulk mailings were cheaper than regular First Class, so PropTop gave his local postmaster about \$300 to open a Business Reply Mail Account. But who would he mail to?

Someone told PropTop that he needed to mail a lot to get any measurable response. So he expected to get about a 2 percent response from his direct mail campaign. After some mental math, PropTop knew he needed to sell 300 IntelliHonkers a month to make it worth his while. To sell 1800 units in the next six months, he'd need to send out 90,000 fliers!

But he didn't have 90,000 friends and relatives. He needed a mailing list.

Fortunately, a quick trip on the net yielded several list brokers, including Dunn & Bradstreet. But these all seemed very pricey. Besides, none of the list brokers knew anything about robotics. So he needed to get a mailing list of the people he wanted to sell to: fellow roboticists.

**Before trusting a mailing list with your fliers and catalogs, consider sending postcards with "Address Service Requested."**

Being more confident than most, he simply called up a dozen robotics-related businesses, and asked for their mailing lists. The replies varied. Some said their lists were private, some were polite but didn't take him seriously, and some didn't have lists that were very big anyway.

A couple of friends gave him a thousand names, including Bill and Hillary. Including himself, 12 times. Including blank spaces and addresses that couldn't possibly exist.

PropTop finally found several businessmen who would sell lists for 10 cents a name. Reasonable. The going rate. So he invested \$1000 into 100,000 names and ordered his fliers printed for mailing. The printer said he knew all about postal regulations, thank Deus!

**Test your mail piece. Don't just fax a copy to the mail design official. Take it down in person, discuss it, and actually MAIL A FEW PROTOTYPES.**

FileMaker Pro and Microsoft Access did some de-duping, and spreadsheet printouts helped him see the problems on a printout, but he new he would need a professional mail house

to do the mailing. His fingers walked through the Yellow Pages and the mailers told him that he could earn discounts with the post office if his mail was marked, sorted, bagged and tagged properly.

**Meet quite often with your local postmaster and the folks who will handle your business account.**

It started to sound complicated. So PropTop asked his postmaster for the number to the postal business center. There he took a free one-day class on mailing requirements. It bored him silly, but he did discover that his mailing costs would be reduced if his mailing database was checked for recency with the government's National Change of Address (NCOA) system. His mass mailing would also need to come with a form full of details about how he sorted, bagged and tagged his mail. His database would need to be "CAS certified." He carried a bunch of literature home that seemed so complex, that he didn't think he'd bother to read it.

No problem, the mail house would take care of it.

So he proofed the blue-lines and color keys at the printer, and the printer delivered a pallet-load of fliers to the mail house. PropTop paid the postage fees to the mail house upfront, happy to learn that all this effort brought his postage way down.

PropTop began to receive his BRM cards. First came the "insufficient address" returns. Then the "Left No Forwarding Address" or "Forwarding Order Expired." If all these addresses were checked, NCOA'd and CAS certified, how could ten percent of his mail budget be wasted this way!

Then PropTop got a slap in the face! The printer had made the cards 1/16th of an inch too wide, so the post office kept them locked up until he paid 76 cents for each "oversized" post card! To add to his troubles even more, he began to notice that a whole lot of his mail didn't get delivered or returned! His uncle, a long-time letter carrier, explained why: "If it looks and feels like bulk mail, and there is any excuse to dump it, even a single digit wrong in the apartment number, there is a certain population of mail carriers who will simply throw it away!" PropTop wondered if the IRS would allow Valium as a business expense.

Instead of Valium, get an Account Representative at the post office business center. Meet with her often, and explain your plans months in advance of an expensive mailing.

Soon he was swamped with replies. Holy Cow! So many people wanted IntelliHonkers, that his mailing earned a phenomenal 8 percent response rate! Now he had several thousand potential customers.

Hmmm.

## **How Hard Could a Mass Mailing Be?**

## Wall Hugger, continued from Page 31

### WALL HUGGING

A wall hugging robot (a wall hugger) sticks with either the left wall or the right wall. Think of it as a person in a dark office, trying to find a light switch. This person moves forward while feeling the wall. For a right-handed person, he/she follows the right hand side. At a junction with an opening on the right hand side, this person feels the turn on the wall and follows to the right. At a dead-end, this person still follows the wall on the right hand side until a U-turn is made.

For a right-wall hugger, the algorithm is quite simple:

```
while robot is not at destination do
  if there is no wall on the right
    hand side then
    make a right turn
  else if there is no wall in front
    move one cell forward
  else
    make a left turn
end if
end while
```

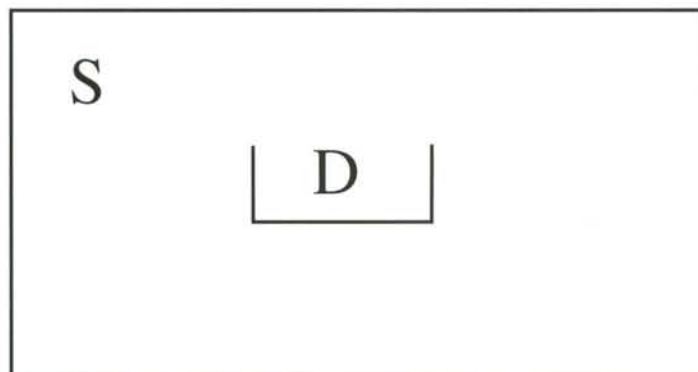


Figure 1: S is the starting point, and D is the destination. A wall hugging robot will never reach point D!

Although the wall-hugging method is simple to implement, it suffers one handicap: in certain cases, it cannot find the destination! Figure 1 shows a simple wall-hugger defeating maze. The destination is in an "island"; therefore, if the robot "swims along the coast" of the lake, it will never reach the island.

RS&T

In Coming Issues: Depth-First, Flood-Fill, and A\* Algorithms

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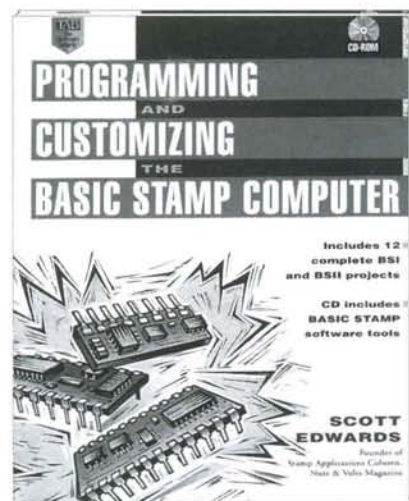
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# Random Firings

Robotics is one of the most exciting frontiers of the Next Century.

And you,  
dear reader,  
are a pioneer.



Wanna Program Stamps?  
See page 51

**T**he more robots we build, in classrooms, labs or home garages, the more we advance society's understanding of the awesome power of intelligent autonomous machines. Indeed, *RS&T exists to promote the use of robots in society by making the science, math & technology accessible.* Sure, we like cool photos and will even discuss science fiction, but our focus is on the serious discourse of robotics.

**Expect future issues to be more technical.** And as always, we'll try to "express Big Concepts using small words" and a lot of illustration.

I think the American Association for Artificial Intelligence robotics competition and exhibition is the "World Series" of robotics, so *RS&T* will be there (see Page 59). Did you see our table at the World Automation Congress-FIRA American Cup in Anchorage? (Thanks to Prof Mo Jamshidi at the U of New Mexico.)

## **RoboCup and MiroSot Results!**

Germans took 1st place in RoboCup and Korean teams dominated the FIRA Robot World Cup (MiroSot, NaroSot). Denmark won the KheperaSot.

If you've no clue what that means, there is help at [www.RobotMag.com](http://www.RobotMag.com), [www.fira.net](http://www.fira.net), [www.mirosot.org](http://www.mirosot.org) and [www.robocup.org](http://www.robocup.org). And read August's *RS&T*. (The contests coincided with the (human) Soccer World Cup during July, so details didn't make press time.)

## **Robot Wars or Robotica in August?**

I'm also fascinated by the world's newest contact sport: Robot Wars is the "Monster Truck Rally" of robotics. This annual contest in San Francisco involves weapon-wielding robots (created by a brigade of "interesting" and intelligent folks). It's dominated by heavyweight radio controlled machines (including Mark Setrakian's 300 lb snake and Christian Carlberg's 8-legged buzz saw). And

we have seen the evolution of autonomous entries that showed promise in '96 and '97. The cheering and sometimes raging crowd of over a thousand spectators around the arena is a spectacle in itself.

Unfortunately, the Robot Wars event will probably not happen this year due to differences between the partners.

However, the competitors themselves, led by Gary Cline of ClineWorks, have organized Robotica. This contest promises to give robot warriors a chance to spill hydraulic blood at the Cow Palace in San Fran, 14-16 August. Folks who want to enter should contact the organizer after reading about the event at [www.ClineWorks.com/Robotica.html](http://www.ClineWorks.com/Robotica.html) and [www.CustomForum.com/RobotWars](http://www.CustomForum.com/RobotWars), a spirited and informational forum hosted by warrior Carlos Bertocchini.

(Robotica is a registered trademark of ClineWorks, and is not affiliated with Robot Wars, which is a registered trademark of Robot Wars, LLC.)

To see scads of photos from previous years' competitions, visit the official RW site at [www.RobotWars.com](http://www.RobotWars.com). To become engulfed in hundreds of photos, taste the narratives, and gain tips on winning, visit [www.RobotMag.com](http://www.RobotMag.com) and browse "Compete, Win, Destroy" and the Links Page. See you at Robotica.

### Subscribers Note

We dreamers at RS&T credit you readers for the immediate and overwhelming support. (In fact, we're late publishing this second issue, because we got swamped processing subscribers in the first month!) Thanks for your patience. We expect the August Issue to come out in the beginning of August. And yes, subscribers will get all six issues (one each month). Questions: write to [service@RobotMag.com](mailto:service@RobotMag.com) or call 888.510.7728.

Readers want technical construction details. Me, too. See Dr Bob Brady's TuteBot on Page 6 for an inexpensive foray into smart hobby robots. Readers want to step up from personal computers to

personal robots. No sweat. Start working with Karl Lunt's SBasic code on Page 40. And check out Lynxmotion's First Step controller, Page 46. This month we're introducing a series of Dr Tak Auyeung's useful maze solving algorithms on Page 30.

### The LIS Robot

Remember the scene in New Line Cinema's *Lost in Space* where young Will Robinson is using virtual reality to control the Big Blue robot? Big Blue repeatedly and relentlessly blew away the evil space spiders with rapidly alternating ray gun blasts from his upper left and right end-effectors. The metal and resin hydraulic monster from Jim Henson's Creature Shop was actually controlled much in this manner. (Two guys wore VR suits, and two held joysticks.) Big Blue and it's unnamed half-pint resurrection provided a tough and dedicated (albeit re-programmable) personal protection robot. We hope you'll consider the imagery that graces this month's centerfold to be inspirational enough to tape to your office wall.

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First, decide how much voltage you plan to deliver to the load. I chose to supply 5 volts to my load, and to simulate that load with a 1k resistor. The closest zener diode locally available had a Vzener of 5.1 V. Using Ohm's Law, I calculated that my components would need to be able to withstand a 0.0051 milliAmp current flow. So all components would have to be rated to dissipate .026 watts. No sweat.

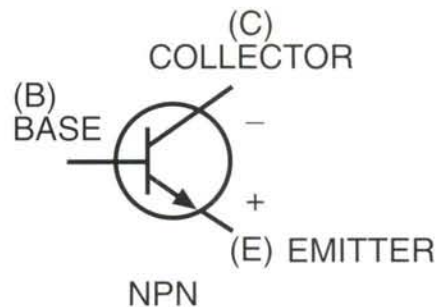
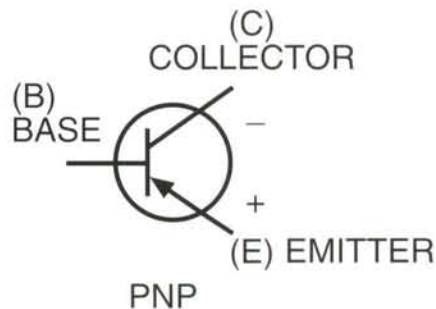
$$\begin{aligned} &\text{Planned (Zener) Voltage} \\ &\div \text{Planned (Load) Resistance} \\ &= \text{Planned Current Flow} \end{aligned}$$

$$\begin{aligned} &\text{Planned Current Flow} \times \text{Vzener} \\ &= \text{Wattage Rating Required} \\ &\quad \text{of Regulator Components.} \end{aligned}$$

Select a resistance for R1, such that

$$\begin{aligned} R1 &= (\text{InputVoltage} - \text{ZenerVoltage}) \\ &\div (\text{LoadCurrent} + \text{ZenerCurrent}) \end{aligned}$$

With my 9 V battery, 5.1 V zener diode, 1k load and the previous calculations, I got a resistance value of 382 . So I chose a resistor in that ball park.



Transistors can conduct from emitter to collector only if sufficient voltage is applied to the base.

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\*No offense intended to pink, drum-beating bunnies

## Resistor Color Code

Resistor values are color coded by several bands on the component body. The first two bands are significant digits, and the third band is a multiplier. A fourth band would indicate the "percent of tolerance." For this project, I just happen to be using 5% (gold) resistors. Using a meter, I noticed that my 10 k resistors are actually 9.9 k. This is well within tolerance, since our circuit values are not critical. See the color code below.

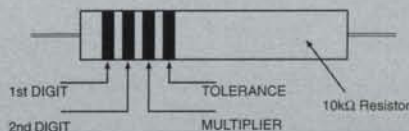
A clear and easy-to-read guide to resistors is in Tech America catalog (free by calling 800.877.0072).

Eventually, you'll memorize the color code, with a mnemonic like this:

### Big Bad Robot Over Yonder Goes Bang Very Good With Girls Swinging Now

Using the first letter of each word, this mnemonic helps you remember the colors and corresponding values:

Big Black 0	Very Violet 7
Bad Brown 1	Good Gray 8
Robot Red 2	With White 9
Over Orange 3	Girls Gold 5%
Yonder Yellow 4	Swinging Silver 10%
Goes Green 5	Now None 20%
Bang Blue 6	



## Flashy Logic Circuits

Let's move on to something more fun: these circuits will have lights. (Light Emitting Diodes or LEDs, to be exact.) A lit LED will indicate the presence of a logical 1 or 0.

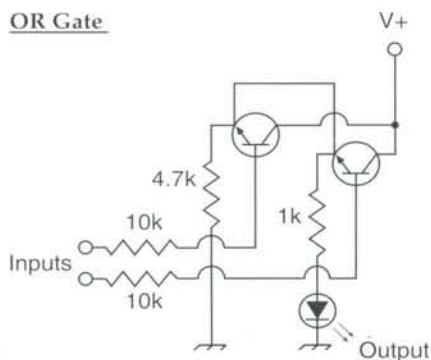
I used a 2N222 "NPN" type of transistor, and a 5 V red LED, Radio Shack Part Number RS276-208. (NPN and PNP refer to the arrangement of silicon wafers inside the transistor.)

By the way, look at the arrow in the transistor symbol. You can remember that this symbol calls for an NPN transistor, if you think of NPN as meaning "Not Pointing iN." Another kind of transistor, a PNP type, would be illustrated by an arrow "Pointing iN Positively."

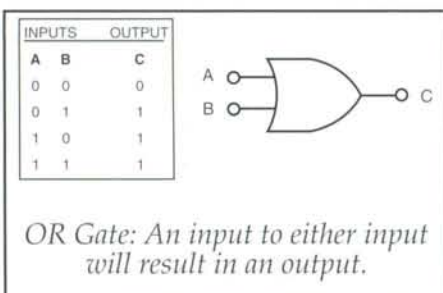
Assemble the NOT, OR and AND circuits on your breadboard as shown in the schematics. As you connect/disconnect each input, predict the outcome, watch the LEDs, and then measure voltages around the circuit to get a practical "feel" for what happens as inputs change.

## Schematics

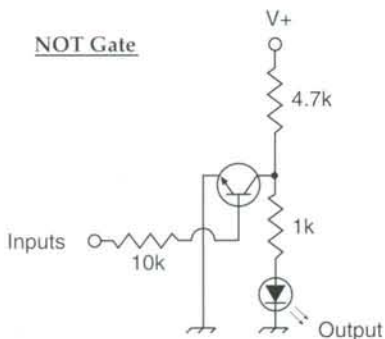
### OR Gate



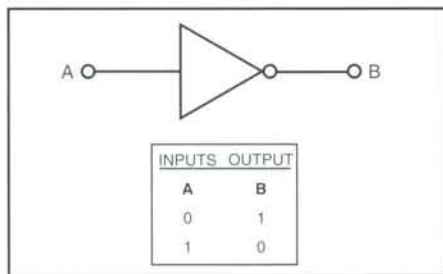
*V+ and Vin as before. The output LED, should demonstrate the Truth Table*



### NOT Gate

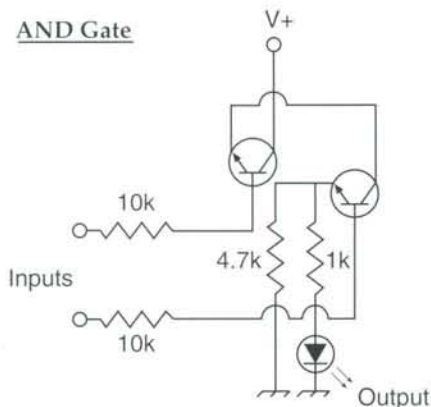


*V+ should be 6 to 9 Vdc.  
Vin should be 4.5 to 5.5 Vdc.  
Output voltage will light (or not light) the LED, inversely of the input.*

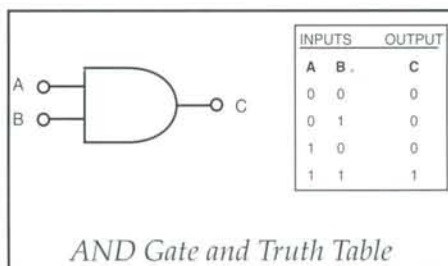


*The NOT Gate simply inverts Vin from 1 to 0 (volts or no volts), as shown in the accompanying Truth Table.*

### AND Gate



*AND Gate: Both input must be 1s to light the output LED.*



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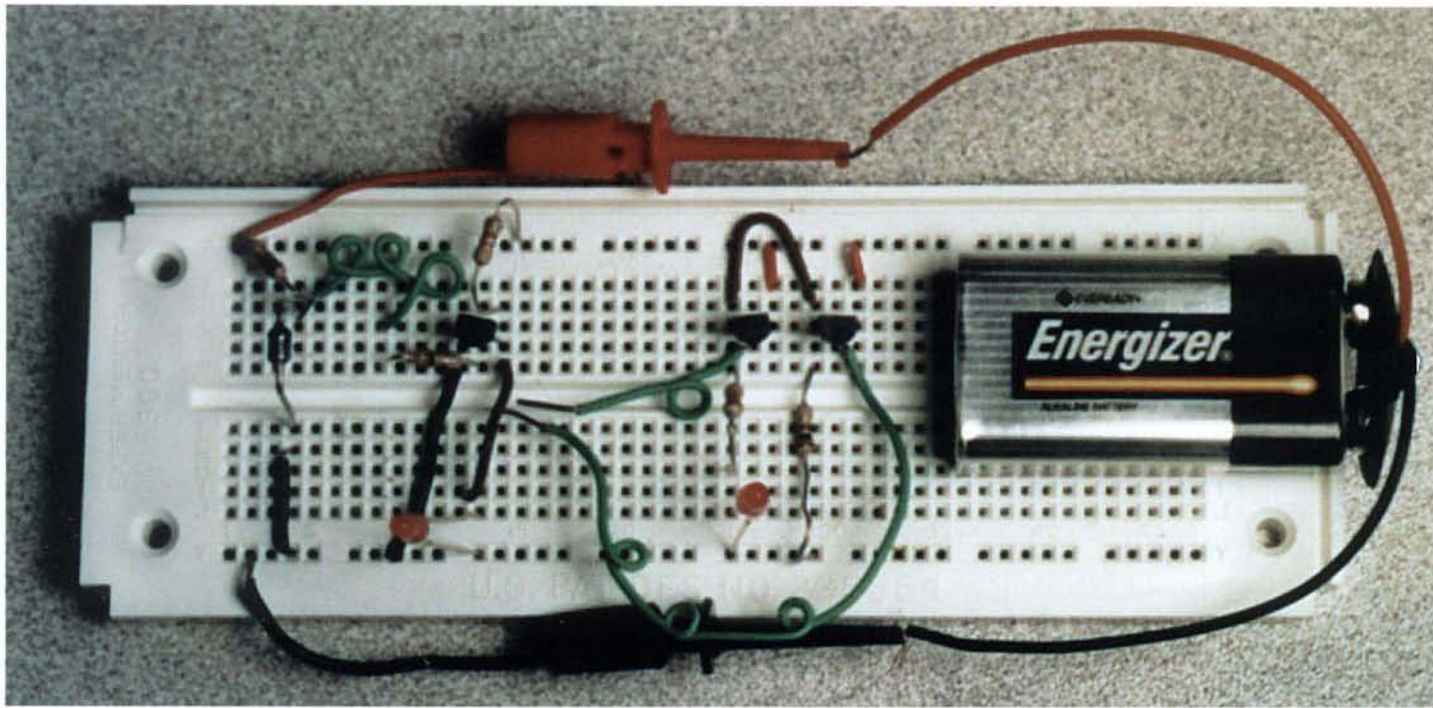
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### Typical breadboard with discrete components.

Left to right: Voltage Regulator, NOT Gate, OR Gate, 9V battery (the green looped wires are movable inputs.)

### Further Study

Get the catalogs mentioned on page 21. Just flipping through them is an education.

Build Truth Tables and test the following logic circuits:

#### NAND Gate

(an AND whose output goes through a NOT)

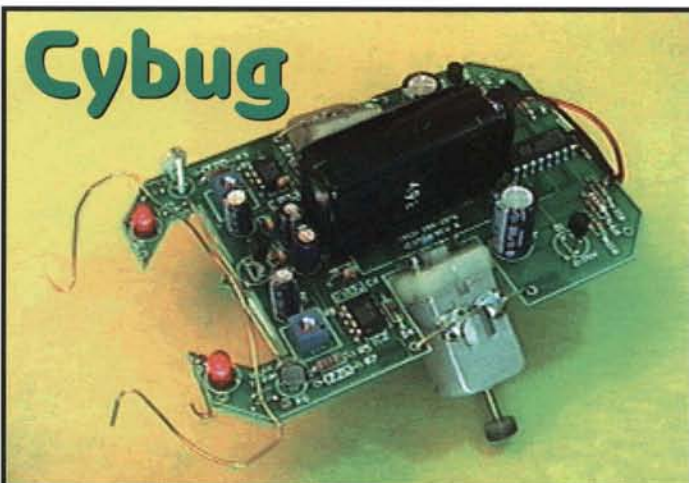
#### NOR Gate

(an OR whose output goes through a NOT)

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www.roboworld.com.sg

When you work with resistors, you'll want to have the resistor color code nearby. I found a whiz-wheel type of decoder at Radio Shack, part number RS 271-1210.





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Alan Schultz of the National Research Lab directs Coyote at AAI -97. Coyote's voice recognition and video scanning are integrated to make the human interface more realistic. The robot can obey such commands as "move forward about 10 inches" and "go a little to the right."

Top: Coyote's rasterized laser takes visual input from Alan. "Come forward this much."

Bottom: Alan says "move to my left", but points to his right. Coyote replies aloud "You pointed in the other direction. I'm confused."

AAAI '97

# AAAI-98

## A Meeting of Metallic Minds

A meeting of great minds – both natural and artificial – will take place this month in Madison, Wisconsin.

The American Association for Artificial Intelligence will host the 15th National Conference on Artificial Intelligence, July 26-30 at the Monona Terrace Community and Convention Center.

One of the highlights of AAAI-98 promises to be the Seventh Annual AAAI Mobile Robot Competition and Exhibition.

### *Hors d'Oeuvres, Anyone?*

The mission of the 1998 competition is to promote innovative research through events that appeal to the media and sponsors. The contests are designed to pose a "low risk to individual or institutional reputations," according to AAAI-98 organizers.

Back by popular demand, the Mobile Robot Competition will consist of the same two popular events that were staged at AAAI-97 – only this year, the *Hors d'Oeuvres Anyone?* and *Find Life on Mars* contests will be more challenging.

The ongoing *Hors d'Oeuvres* event will reward innovation in human-robot interaction. Robots will be let loose in the conference lobby to hand out flyers, make announcements, and of course, offer refreshments.

The *Find Life on Mars* event will demonstrate the latest advances in navigation, task planning, and mapping activities.

### *A Robot Menagerie*

The purpose of the Mobile Robot Exhibition is to showcase current research in robotics that does not fit into either of the competition parameters.

Snakes, manipulators, bipeds, helicopters, and more will be presented and demonstrated. Several indoor arenas for small and medium

RoboCup matches will be available. Furthermore, outdoor venues have been set aside for aerial robots and ground vehicles.

"We're aiming for as much variety as possible," says the exhibition sponsors.

### *Build Your Own*

Again this year, AAAI is hosting a Robot Building Laboratory – and contest – in cooperation with the KISS Institute for Practical Robotics.

The lab will be mostly hands-on: building and programming small mobile robots to do a variety of tasks. The instructors will give the attendees the necessary information to embed their systems in physical agents – mobile robots – that can interact with realistic environments.

Each team will have all the components – and tutorial help – necessary to design, build and program their own robot. The nature of the contest will not be revealed until the beginning of the robot-building lab.

### *Who Are These Guys?*

Founded in 1979, the American Association for Artificial Intelligence is a nonprofit scientific society based in Menlo Park, California. AAAI is devoted to advancing the scientific understanding of the mechanisms underlying thought and intelligent behavior and their embodiment in machines.

AAAI also aims to increase public understanding of artificial intelligence, improve the teaching and training of AI practitioners, and provide guidance for research planners and funders on the importance and potential of current AI developments – and the implications for the future.

Official webpage for AAAI-98: [www.aaai.org/Conferences/National/1998/aaai98.html](http://www.aaai.org/Conferences/National/1998/aaai98.html)

Webpage for the Mobile Robot Competition and Exhibition: [www.cc.gatech.edu/aimosaic/robot-lab/aaai98/](http://www.cc.gatech.edu/aimosaic/robot-lab/aaai98/)

Rules for *Hors d'Oeuvres, Anyone?*: [www.aic.nrl.navy.mil/~schultz/rules.html](http://www.aic.nrl.navy.mil/~schultz/rules.html) Rules for the *Find Life on Mars*: [dangermouse.uark.edu/aaai-98/life-on-mars](http://dangermouse.uark.edu/aaai-98/life-on-mars)

Robot Building Lab: [www.aaai.org/Conferences/National/1998/Robots/aaai98-rbl.html](http://www.aaai.org/Conferences/National/1998/Robots/aaai98-rbl.html)

KISS Institute for Practical Robotics: [www.kipr.org](http://www.kipr.org) Monona Terrace Community and Convention Center: [mononaterrace.visitmadison.com](http://mononaterrace.visitmadison.com)

An email list-server concerning the AAAI-98 Robot Competition and Exhibition has been set up. To subscribe, send an email to [majordomo@cc.gatech.edu](mailto:majordomo@cc.gatech.edu) with "subscribe *aaai98*" in the message body. To post something to the group, email it to [aaai98@cc.gatech.edu](mailto:aaai98@cc.gatech.edu).

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*The Texas Robotics & Animation Center Laboratories (TRAC Labs) ServeDroid approaches Benjamin Jones at the Hors d'oeuvre competition at AAAI-97. A pyroelectric sensor differentiates people from inanimate objects. The top carries candy and a laptop computer to display a face which turns in the direction of the closest sonar range ready.*



AAAI '97

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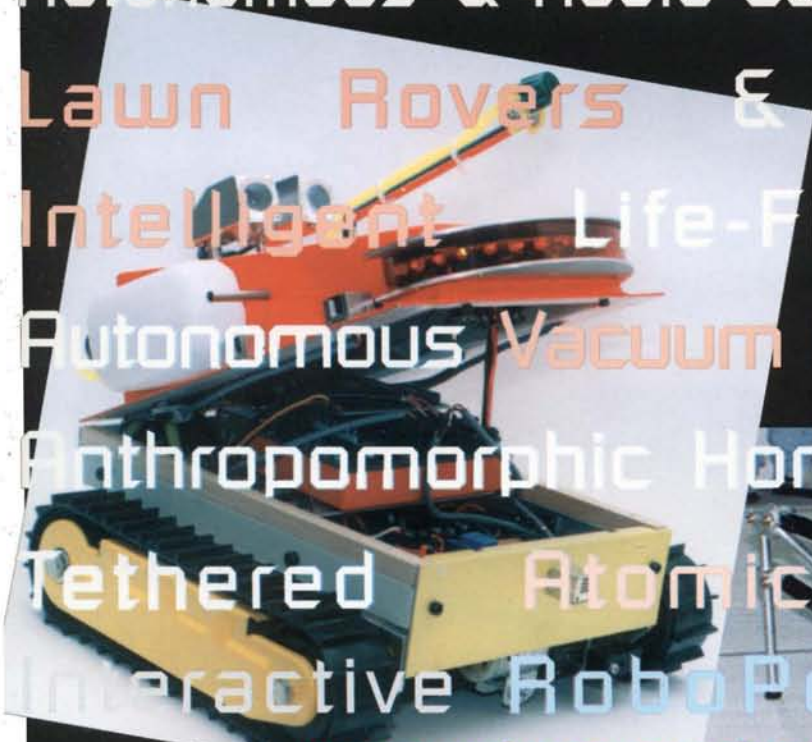
Intelligent Life-Finding MarsBot

Autonomous Vacuum Cleaners Lunar Rov

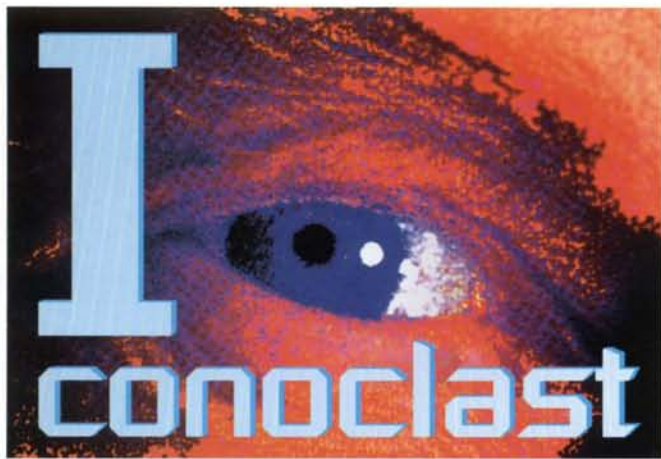
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# Software Viagra

If your only tool  
is a hammer  
then every problem  
looks like a nail.

The common conception of a mobile robot is its physical embodiment. The metal, plastic, nuts-and-bolts contraption that moves, grabs, and flashes lights, perhaps even talks. But it's the software that supplies a robot's *'elan vital*, its vital force. Without guiding principles, a robot would just be an unintelligent inanimate hunk of junk.

But I think this attitude has gone too far; it's starting to replace well-designed hardware. Wheels not aligned? Not to worry, the PID (process identifier) algorithm will take care of it. Cross talk in the sonars? That's OK, the signal processing software will sort it out.

The view that software is the preeminent ingredient in a robot – and the only part worth careful development – stems in part from the fact that most mobile robot researchers have backgrounds in computer science or artificial intelligence. Got a problem? Software's the answer. The syndrome operating here is a variant of "If your only tool is a hammer, every problem is a nail."

I'm certainly not opposed to software, software control of robots, or development of software tools, languages and so forth. Nevertheless, simply put: Software processing is not a good substitute for careful hardware design.

Permit me a humble example. I recently twisted my knee severely, and yet, all my "software processing" doesn't correct for the proper functioning of this joint. While my software work-around provides a built-in fault tolerance and allows me to proceed instead of being crippled, I can only operate in a very diminished capacity.

My point is that if my knee were ill designed to begin with, this diminished capacity would be the best I would expect, and the best I would know to expect. How much better then could our robots do, if more consideration were given to their mechanical design?

Many researchers begin their robot creations with some generic, commercial robot base, which usually has a bevy of built-in collision-avoidance detectors. I understand the convenience and initial timesaving concerns that lead to

purchasing a ready-made base, but is it the best platform for developing an intelligent robot? It's sort of like buying a suit off the rack. It's less expensive and will fit pretty well, but it's not going to perform as well as one that's expertly tailored for an individual's size, shape and character. Any factory-made robot, or suit, is going to have many compromises built into it.

I recently purchased an excellent book on robotics, *Artificial Intelligence and Mobile Robots: Case Studies of Successful Robot Systems*, edited by

Kortenkamp, Bonasso and Murphy. The first four chapters are case studies pertaining to mapping and navigation. All the robot bases used in these studies were commercially purchased units, with the standard sonar ring around their girth. Only one of the robots was modified to customize the sonar arrangement. (The placement of 15 of the usual 24 standard Polaroid sonars was rearranged differently around the robot.)

That robot, *Dervish*, also had the simplest sonar-processing scheme for detecting obstacles and deriving features from its surroundings. None of the other robots could sense small obstacles in their path – *Dervish* could. None could sense that they were about to fall down a flight of stairs – *Dervish* could. None could sense an impending clunk in the head by a tabletop – *Dervish* could. *Dervish's* sonar arrangement was tailored to the task at hand. The other robots were merely convenient software fodder.

Or were they? Much of their software development was devoted to overcoming the built-in factory limitations!

Now, I'm not knocking the commercial platforms; I wish I could afford one. Many of us have computers but not machine shops. So it's easier, both in concept and implementation, to think of software control than to think of mechanical invention. What I want to advocate here most strongly is: When designing and building robots, give extra consideration to the mechanical aspects. An appropriate mechanical design is the first step toward building a successful robot. –The Iconoclast

---

*When I twisted my knee,  
my brain provided a  
work-around.  
But I was still limping.*

---

## July 26-30 AAI-98 Mobile Robot Competition & Exhibition

Madison, Wisconsin • [www.aaai.org/Conferences/National/1998/robots-98.html](http://www.aaai.org/Conferences/National/1998/robots-98.html)  
[www.cc.gatech.edu/aimosaic/robot-lab/aaai98/](http://www.cc.gatech.edu/aimosaic/robot-lab/aaai98/) (see page 60)

## August 1-3, International Autonomous Underwater Vehicle Competition

Panama City, Florida • [www.auvsi.org/auvsicc/auvcomp.htm](http://www.auvsi.org/auvsicc/auvcomp.htm) • [bales@mit.edu](mailto:bales@mit.edu)

## August 8, Robo Expo

Regency Plaza Hotel, San Mateo, California  
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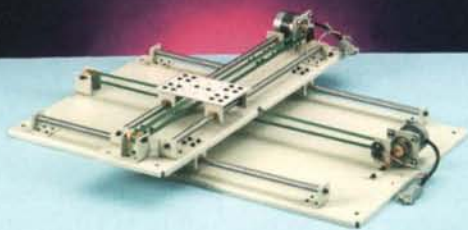
## August 14, International Aerial Robotics Competition

Richland, Wash. • [avdil.gtri.gatech.edu/AUVS/IARCLaunchPoint.html](http://avdil.gtri.gatech.edu/AUVS/IARCLaunchPoint.html)  
[robert.michelson@gtri.gatech.edu](mailto:robert.michelson@gtri.gatech.edu)

## August 14-16, Robotica

enthusiasts should check [www.customforum.com/robotwars/](http://www.customforum.com/robotwars/) AND  
[www.ClineWorks.com/Robotica.html](http://www.ClineWorks.com/Robotica.html) for details. Also see page 54

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## August 15, Robo Expo

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## August 22, Robo Expo

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[www.RobotStore.com](http://www.RobotStore.com)

## September 6, Dragon\*Con Robot Battles

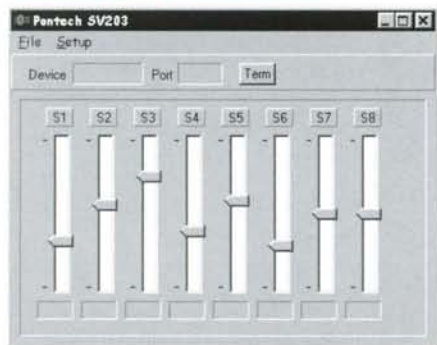
Atlanta • [www.dragoncon.org/panels/robot.html](http://www.dragoncon.org/panels/robot.html)  
[kellyl@cris.com](mailto:kellyl@cris.com)



## September 20, Robo Expo

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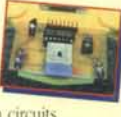
### Mega Hexapod Walker Kit #3-423 \$375.00

It's huge! 12 servos drive this platform with full control and major strength. Add your own Mini SSC2's, a controller (Stamp2, BOTboard) and some sensors for advanced autonomous behavior!



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Give your robot the gift of Vision! This Infra-Red Proximity Detector can detect an object from 10 - 30 cm away! Connect to a Stamp, HC11, PC parallel port, or your own circuits.



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