

*Getting to Know Professor Rodney A. Brooks*

# ROBOT

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OUR SEVENTH ISSUE • FEBRUARY/MARCH 2000

**Robotic Arm Trainer from OWI**

**Building & Programming  
a Small Mobile Robot**

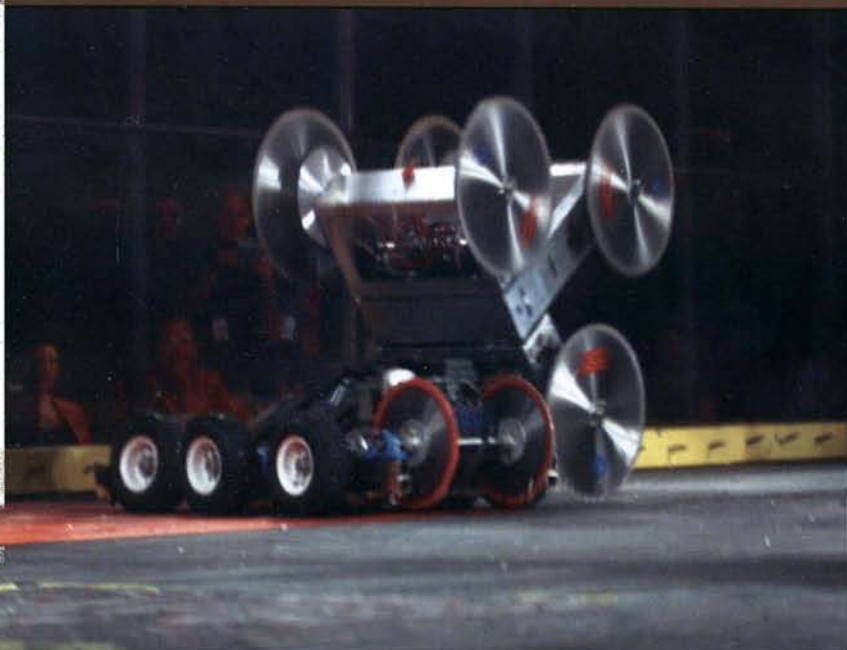
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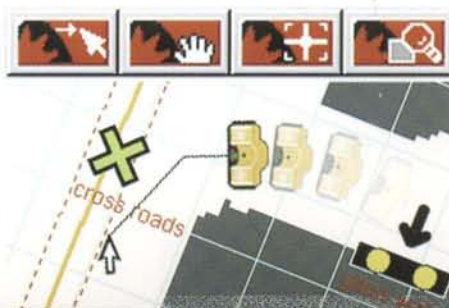


#### CYE Product Specifications:

- Weight: 9 lbs. (4 kg.)
- Dimensions: 16" x 11" x 5" (40 x 28 x 13 cm.)
- Towing Force: 7 lbs. (3.2 kg.)
- Energy Capacity: 24 hours - no motion; 5 hours - motion, 1-2 hours - towing upright vacuum
- Ded-reckoning accuracy: less than 5 degrees of heading error per 50' of travel
- Radio Range: 100' through walls, 300' line of site
- Includes: Map-N-Zap software on CD-ROM, manual, PC radio pod, Cye Home Base
- PC Requirements: WIN95 or WIN98 with a spare DB-9 COM port

The Cye robot offers ded-reckoning that works and a powerful and extendible GUI. Cye comes with a 19200 baud radio link connecting him to your PC. You can use the Windows application "Map-N-Zap" to control Cye, or create your own VB or VC++ software using the Cyesrv Windows ActiveX which provides 71 methods, properties, and events.

Cye can carry over 25 pounds in his wagon at up to 3'/sec. Cye can vacuum with the Cye Vacuum Attachment, a cordless vacuum with powered brush. An RJ45 port mounted on Cye provides connectivity to peripherals. Cye sells complete with charging station for \$695 at [www.cyerobot.com](http://www.cyerobot.com). The Cye-*sr* model (\$845) adds sound response. Cye-*sr* responds to clap sequences and music.

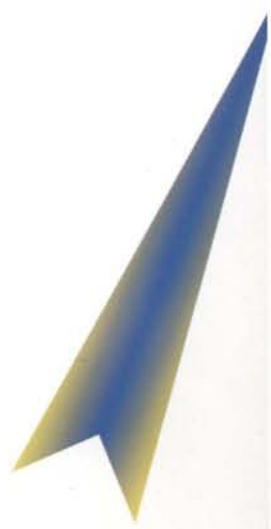
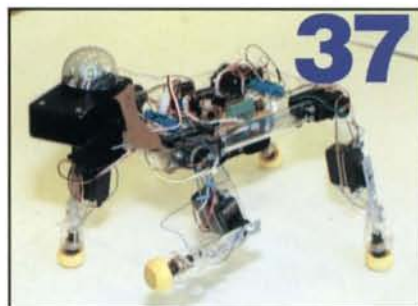
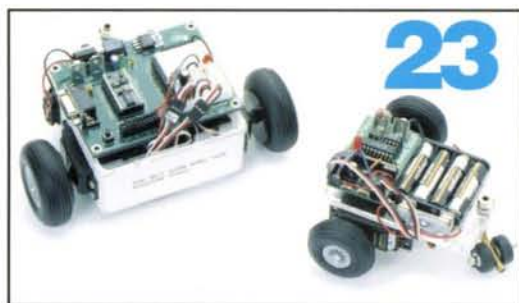
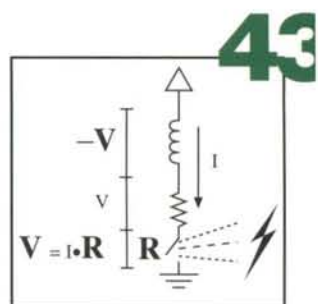
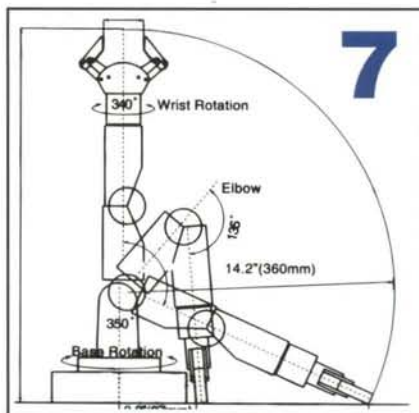


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Michael A. Greene  
Publisher & Editor-in-Chief

Eugene P. Ronan, Technical Editor

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John Piccirillo, PhD, Contributing Editor

Kristine Marie Wills, MD  
Contributing Editor

Elizabeth A. Walker, Circulation Manager

D Dayne VanPelt, Marketing Manager

Teddi Deppner, Webmaster

**AUTHORS IN THIS ISSUE**Tak Auyeung  
Gene Burbeck  
Ken Gracey  
John Iovine  
Russ Miller  
Mark Robillard  
Chuck Schoeffler

ART &amp; DESIGN, Amy Ellis

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# Our Mission:

 to immerse readers in 21st century robotics technology with in-depth reports on real robots, and through hands-on adventures with home, classroom, and sport robotics.

## News Since Last Time

**Probotics & Hoover** teamed up to make a light-weight, reasonably affordable robot vacuum cleaner. Probotics Cye robot, with wagon and custom vacuum attachment, roamed our halls at RS&T for several months, proving that even editors can program home robots. Yep, it actually cleaned our carpet autonomously, and returned directly to its electrical feeding station when it needed a charge. Interesting toy-cleanup feature: whenever Cye approached, our RC cars would suddenly drive off at high speed.

**Advanced Design "Robix"** was the first-ever "robots only" company to exhibit at Comdex in November. RS&T's wandering publisher met Evan and Charlene Rosen, who set up a mock kid's bedroom to demonstrate the ease of learning to use their educational arm and its programming interface. A challenge to the rest of us: more robot companies need to get ready now for Comdex, Nov 2000.

Basic Stamp maker **Parallax Inc** had the busiest booth in their section of the convention hall. Engineers Chuck and Chip Gracey, Russ Miller and others showed off several compact robot designs, Orbot, GrowBot, and the made-for-teachers Boe-Bot. Parallax recently completed a US tour, teaching teachers how to use their Basic Stamp. See [stampsinclass.com](http://stampsinclass.com) and [parallaxinc.com](http://parallaxinc.com).

Also sighted at Comdex: **Mondo-tronics' Robot Store** owner/engineer Roger Gilbertson demonstrated how his Muscle Wire proved so useful and lightweight, that it was incorporated into the Sojourner rover and sent to Mars. You remember the "successful" Mars mission in July 98? Muscle Wires are showcased at [robotstore.com](http://robotstore.com).

Some RS&T insiders are pretty sure that the **Mars Polar Lander** was shot down in retribution for our destruction of the Martian's probes during their visit to Earth in 1933. Reference: *War of the Worlds*. Some scientists think it slid down a mountain. Moon walkers Neil and Buzz wouldn't have flown like that.

**BattleBots played Las Vegas**, November 17. There were some amazing upsets and trouncing victories that surprised the robotic combat community. Kudos to Trey Roski, et al, for picking up the combat banner and waging two major competitions in a single year. See the action on pay per view, Jan 29. See [battlebots.com](http://battlebots.com) for the latest.

The **Seattle Robotics Society** ([seattlerobotics.org](http://seattlerobotics.org)) is doing a magnificent job of expanding robotics in the Northwest. Their Robothon at the Seattle Science Center, Oct 23, featured firefighting home-builts, dancing Aibos, and choreographed Cognachrome Mach 5s from **Newton Labs**. America's West Coast Sumo King Bill Harrison's autonomous sumo event was a smash hit as always. (I learned not to drop anything in his workshop; you'll never find it again, amidst all the tools, machines, design papers, and robot parts). Fifty robots showed for eight events. Steve Richards of **Acroname** lectured on subsumption architecture, an ingenious approach to designing robots for the real world. Lots of good tech info at [acroname.com](http://acroname.com).

Contributing Editor John Piccirillo's **Robotics Mini-FAQ** was updated and posted on RS&T's website ([robotmag.com](http://robotmag.com)) to give folks a quick-to-read introduction to hobby robotics. Thanks, John.

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# FEEDFORWARD: SELECTED REVIEWS

## What's Out There?

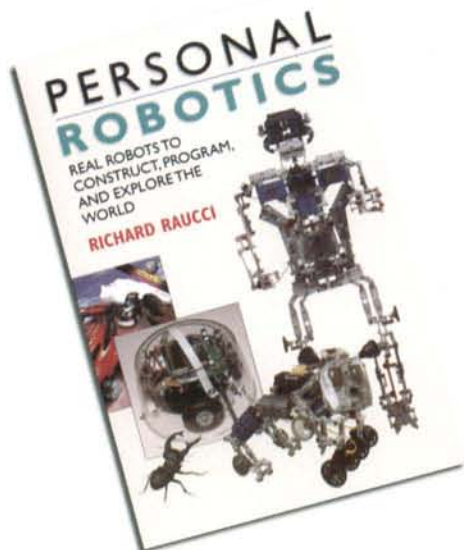
Review by Mike Greene

### Personal Robotics:

#### Real Robots to Construct, Program and Explore the World

BY RICHARD RAUCCI

A K Peters, Ltd., Natick, Massachusetts, 1999



This robot book distinguishes itself immediately as being one of the very few surveys of several specific robots. With down-to-earth information about each, the reader can make an intelligent choice of which robot to buy or build. Even the introductory pages, which present a historical perspective of society's view of robots, androids, and automatons in reality and fiction, are interesting and informative. Most of the book, however, is dedicated to fielding the question: *What's out there?*

Only a very few books exist that discuss a handful of specific robots, and rarely can a reader find such unbiased information on kit-built designs. Unlike this easy-to-read survey, most "descriptive" books are difficult to absorb. What's a beginning roboticist to do? How do you choose a robot kit for a class project, for your hobby, for a gift?

Author Richard Raucci spent months playing on his knees building, programming and running a herd of robots selected by common-sense criteria. Is it a *real* robot? Is it *interesting*? (He ignores radio-controlled toys.) Then, bravely, Raucci gives his real-world opinion on the pros and cons of each model. He recommends hobbyist robots (mostly kits), and experimenter toys and kits as low as \$50. At the high-end, he shows us a commercial grade machine aimed at the school and research markets for under \$3000.

This 200+ page compendium of first-hand hands-on experiences with walkers, rollers and arms from Learning Curve-Robotix, Capsela, Lego (including MindStorms), SilverLit, Johuco, OWI, Parallax, Solarbotics (BEAM), Robix, FischerTechnik, A.K. Peters (Rug Warrior), and JCM Electronics (CyBug) robots is a valuable aid for teachers, hobbyists and parents. He reports on the results of his field tests, the robots' features and functionality, and their possibilities for expansion. He includes sample programming code and screen shots to give the prospective buyer a sneak peek at the interface and skill level required to build and operate these robots. Finally, he specifies sources that have these machines available for purchase.

The sophisticated autonomous Pioneer robots from ActivMedia earn their own chapter in this book, perhaps because they are the "...best-priced robots in their class" and "A noble attempt to bring a full-fledged professional robot near to the education/consumer market." Raucci doesn't cover other high-end

research robots, perhaps because the others are too expensive for mass consumption, too specialized or too complicated for his intended audience. But *Personal Robotics* goes a long way toward answering the question: *What's out there?*

It's hard to keep up with technology today, however this information was up-to-date through mid-1999. As more manufacturers enter the field, more model lines will be offered than ever before. Readers should not therefore, conclude that this book is the last word. Instead, the author and publisher have set forth a challenge for the personal robotics information industry: Will anyone be able to keep us up-to-date on every new major product line?

Raucci did a good deed by presenting this broad-stroke review of some of the most popular robots available to our readership. I commend publisher Klaus Peters for bringing this book promptly to market. Without *Personal Robotics*, we would all be less informed.

RS

#### Personal Robotics: Real Robots to Construct, Program, and Explore the World

by Richard Raucci, 1999

ISBN 1-56881-089-X, 208pp, amply illustrated

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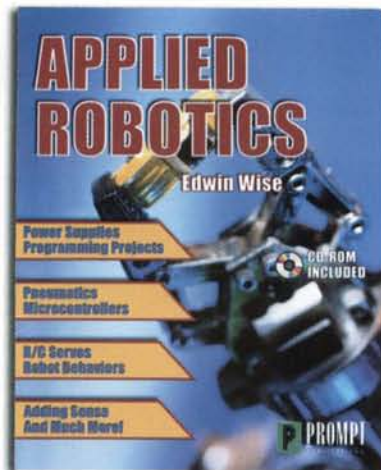
## One Piece at a Time

Review by Tak Auyeung

### Applied Robotics

by Edwin Wise

Prompt Publications, Indianapolis, 1999



There is a lot of material in this book, touching on many diverse areas of concern to students and hobbyists. Some of the major topics include electronics, mechanical design, low-level software device drivers, high-level fuzzy logic and pneumatics. How can anyone ever hope to solve the myriad desperate problems presented when building a complete robot? It's like trying to eat an elephant! How do you do that?

Author Edwin Wise supplies his expertise in a practical and hands-on project-oriented format. Readers can follow the text and actually build the projects.

The first five chapters cover topics common to most small electrical mobile robots: chassis, gearing, power supplies, drive circuits, speed control, simple sensing, etc. The discussions include hands-on information as well as theoretical explanations. The book uses extensive parts list, diagrams and photographs to make the projects easy to follow. Wise also explains how each design or component works, as well as important selection criteria for specifying parts.

Chapter 6 is where the fun really begins. It adds behavior to the robot described by the previous five chapters. Any reader with some knowledge of electronics should find it easy to read up to and including chapter six. Indeed, robots that exhibit basic behavior can be constructed based on the first six chapters.

Chapters 7 and 8 cover the basic software and hardware operation of a microcontroller

(MCU). This is where some readers may have trouble understanding *how* the components work. Nonetheless, there are enough part lists, instructions and circuit diagrams to help the reader build the projects.

Chapters 9 and 10 cover the theory and implementation of fuzzy logic respectively. While Chapter 9 contains a general discussion of neural net and fuzzy logic that all readers can understand, Chapter 10 includes additional technical details about the MCU as well as actual Fuzbol (a C-like fuzzy logic programming language) code. Readers with some processor architecture knowledge and C programming experience should find chapter 10 interesting. Others may understand the general idea but find the details distracting.

Chapters 11 to 13 resume to discuss additional general topics related to robotics, such as distance/position sensing/encoding, R/C servo applications and pneumatic designs. In particular, Chapter 13 is a mini-guide to pneumatics, including explanations of the physics, pneumatic devices and their symbols and basic design issues.

From the educational perspective, this book presents a complete overview of the diverse technologies in a modern robot. However, beginners may find themselves struggling in chapter 7, 8 and 10 due to the amount of technical details. While the author provides some explanation for the microcontroller (MCU) and software concepts, beginners probably need more background materials before they understand MCUs and software development enough to develop their own robotic software applications.

This book is highly recommended for robot enthusiasts with some background in the electronics and software of computer-based controllers. The included fuzzy logic application tool (Fuzbol) presents a practical means to experiment with rule-based robotic behavior.

Answering the original question, how do you eat an elephant? Edwin Wise's instructive style in *Applied Robotics* demonstrates the practical method: one piece at a time.

R&S&T

### Applied Robotics

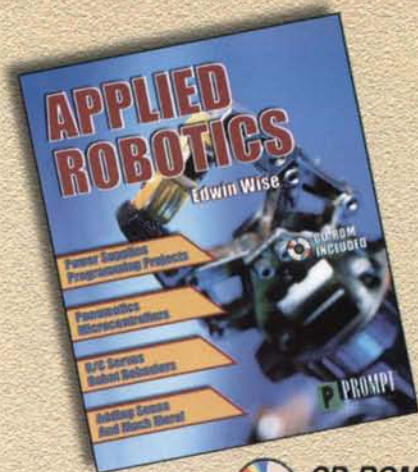
by Edwin Wise

234 pp plus sample program code listings, list of suppliers, bibliography & CD-ROM. Well-indexed

ISBN: 0-7906-1184-8

Prompt Publications, Indianapolis

# EXPAND YOUR KNOWLEDGE



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## APPLIED ROBOTICS

by Edwin Wise

This book will guide the hobbyist through the issues and challenges of building a working robot. Each chapter builds upon the previous one, extending a core robot project throughout the book. Each chapter also includes advanced information and references to other books and internet sites for further information. Also included is a CD-ROM containing author notes and projects.

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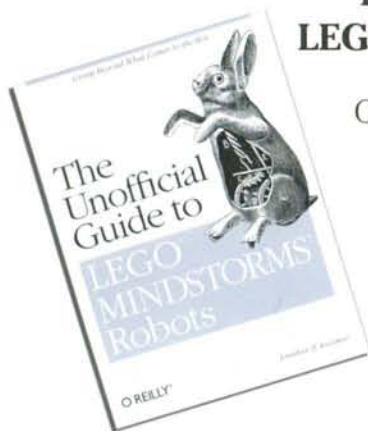
## Programming Foundations: One Brick at a Time

Review by Mike Greene

### The Unofficial Guide to LEGO® MINDSTORMS™ Robots

by Jonathan B. Knudsen

O'Reilly, Sebastopol, CA 1999



Occasionally, we come across a unique and satisfying book on a leading edge topic, and here is one of the best. This book is, to date, the most complete and intellectually beautiful resource for veteran and freshman programmers who want to explore the myriad methods of cross-compiling for the robotic embedded system that is the brain for Lego's MindStorms Robotic Invention System.

Longtime followers of RobotMag.com were introduced to the progenitor of Lego's RCX brain, the Programmable Brick invented by MIT Media Lab's Fred Martin, back in 1996, which was already a developed research tool. Readers were introduced to Lego's RIS in RS&T Issue 5. Now, O'Reilly has published the first comprehensive book for programming MindStorm robots.

Veteran Java programmer, book author and online columnist Jonathan Knudsen has bravely hunted in an enormous jungle of interpreted functions, teleoperated interactive programs and autonomous compiled multitasking threads to bring home a truly new and incredibly useful introduction to alternative programming for MindStorms.

In fact, anyone who thinks that MindStorms is "just a toy" for 11-year-olds will be converted upon scanning this well-supported, excellently written and superbly edited book. Knudsen clearly shows that the MindStorms RIS is a roboticist's tool.

It's remarkable to see a "software" book explaining hardware construction, but that's a natural result of the interdisciplinary nature of robotics.

Even the birth of this book is noteworthy: this book about alternative programming environments appeared prior to any "official" book.

But that's natural for 21C information flow. Hackers reverse-engineered the RCX brain immediately after the kit was released. Where there was an information vacuum created by popular demand, dedicated nerds supplied the needed data via the internet.

Knudsen's purpose is to satisfy your exploratory urge. "Once you've built a few robots and written a few programs, you'll probably be itching for *more*: more complex robots, more powerful programming environments, more sensors, and more fun. This book will take you there."

Knudsen leads a silicon safari, showing us several complete, well-documented and useful programs. Some chapters are actually quick-starts for various environments, including Not Quite C, Programmable Brick FORTH, and legOS.

Since this book is about alternative methods, it ventures outside of Windows, giving some direction for MacOS and Linux users. Plus he introduces many URLs for parts, code, and ideas.

We benefit from programs using cooperative multitasking, preemptive multitasking and subsumption at a level understandable to inexperienced programmers. The whole book is accessible: hardware sections are useful for first-time robot builders, and software sections do not exclude any interested technologists.

Importantly, Knudsen details the foundation of every Lego invention, the bricks. There are over 100 detailed b/w illustrations. It's easy to see why students of robotics have used Lego products for over a decade: physical embodiment of intelligent behaviors are easily recast during trial-and-error experimentation.

And for those without fear of a little soldering and a Dremel tool, Knudsen explains how to make your own sensors-on-a-brick. Example: he multiplexes several touch sensors to a single RCX I/O stud, using a bitmask to determine which bumper was hit.

In short, author Jonathan Knudsen and editor Mike Loukides successfully extended Fred Martin's invention beyond the labyrinth halls of MIT, past the toy store shelves, into the hands of serious behavior researchers, technology teachers, and self-taught robotics experimenters.

RS&T

### The Unofficial Guide to LEGO® MINDSTORMS™ Robots

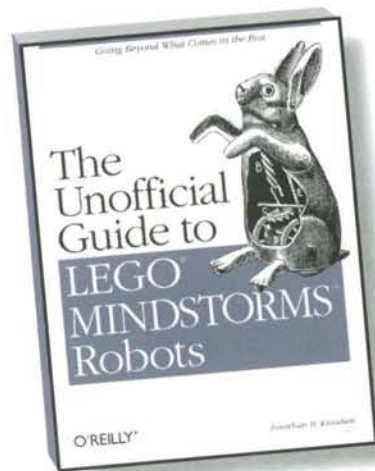
by Jonathan B. Knudsen

248 pp with sample program code listings, lists of suppliers, and index.

ISBN: 1-56592-692-7

O'Reilly & Associates, Sebastopol, CA.

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# OWI Robotic Arm Trainer

## A Study in Arm Engineering

by Mark J. Robillard



Anyone who has read my articles over the years has probably noticed that when it comes to supplying a starting point for robotics, I tend to support the local toy merchant. Toys, although intended for children, are designed by adults. More often than not, the designer must surmount many engineering difficulties to accomplish the necessary price/performance ratio that makes a product successful.

Over the years several products have been introduced in the area of educational robotics. Occasionally I find one that really stands out.

Seventeen years ago I introduced the robot experimenter to the Tomy Armatron (later distributed by Radio Shack) robot arm. Never before in the history of toys had a product with so much robotic functionality been made available at such an affordable price. Armatron included six degrees of freedom with parallel jaw grippers that could grasp and lift eight ounces, all for under \$50.00.

Armatron had one motor and an elaborate system of gears and cams to create six independent motions. Mechanical joysticks moved levers and selected cams. The only way to externally control the toy was to emulate the operation of the joystick using motors, solenoids and servos. Thus, this impressive mechanical design proved a formidable task for computer interfacing.

Since that time, several vendors have offered arms but they never had the 'WOW' factor of Armatron, until now.

Late last year OWI Corp. introduced a new robot arm trainer. The new arm is called the OWI-007 Robotic Arm Trainer. The trainer has capabilities usually found only in much more expensive experimental arms. Incorporating five separate gear motors, manual control is accomplished through a series of simple up-down center-off switches. Figure 1 illustrates the functional capabilities of the product.

The arm rotates left or right. The elbow and shoulder raise and lower. The wrist rotates and the two-fingered parallel-jaw gripper opens and closes. Not bad for approximately \$70! Converting 1982 dollars into 1999 currency indicates that OWI has actually improved on the price/performance features of Armatron.

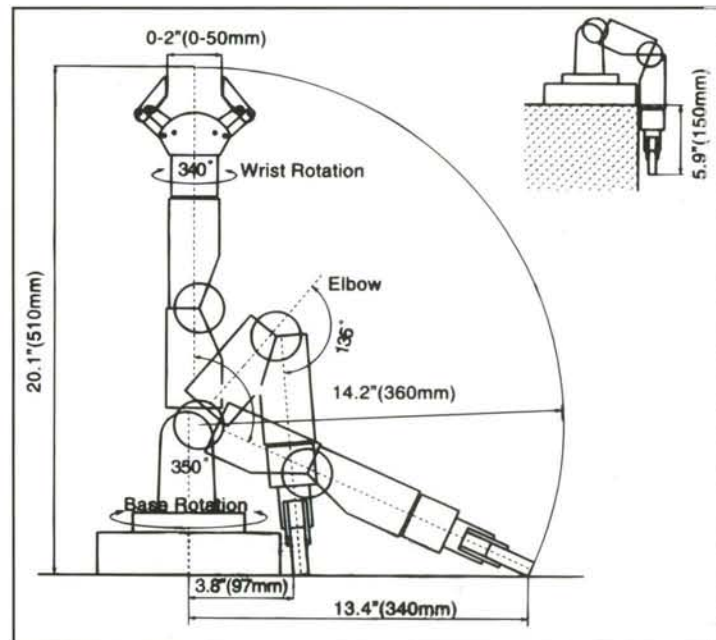


Figure 1. OWI Arm Specifications

Thanks to OWI for art permissions.

Using the arm is addictive after you insert the batteries. If you buy one for yourself, either get another for the kids or don't let them see it.

The purpose of this article is two-fold. For those of you who have not investigated the OWI arm I present a thorough review of the mechanical design concepts that make it outstanding. You will learn some simple yet elegant mechanisms. If you have purchased one, I'll show you how to add position feedback to each of its joints and how to interface your embedded controller.

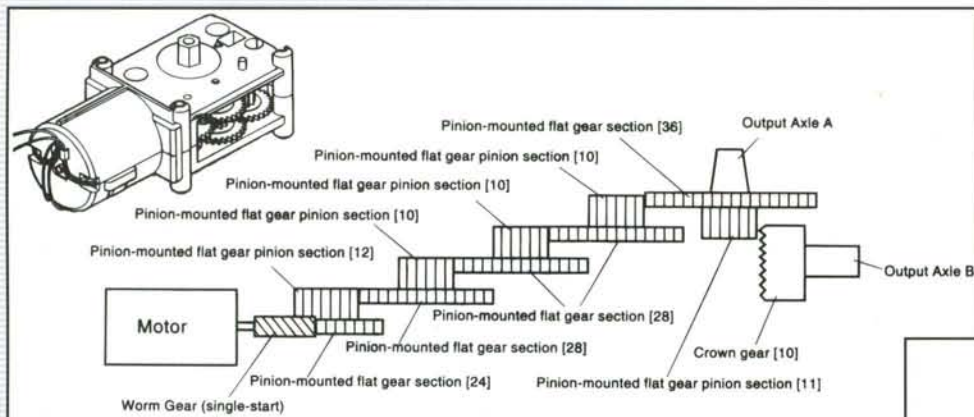


Figure 2. Gear Motor Internal Details

## OWI Arm Basics

The OWI arm relies on five specially designed gear motors for movement. Each motor provides ample torque for movement while consuming minimal current. This minimal requirement is due to the mechanical advantage gained using a multitude of gears. Figure 2 depicts the internal arrangement of gears within each motor unit. The motors run on as little as three volts.

The simple DC motor in each joint is controlled by providing a positive or negative three volts. This can be done through manual switches (like the supplied controller), low current relays or standard H-Bridge drivers. OWI offers an optional PC-based electronic control unit plus software.

Providing electronic control of the motors is only half the story. When attempting to add computer-based intelligence to an arm, knowing where the joints are and when they reach their intended destination is the remaining half.

Unfortunately, the OWI arm includes no provision for direct position feedback. Even the OWI control interface and accompanying software do not rely on actual position. Without feedback one can only use time-based open-loop control. This is where you specify the amount of time in seconds that a motor is activated. As easy as it seems, this method yields unpredictable results. Motors don't always stop immediately when commanded. Varying loads on the joints will tend to slow them down thus throwing the timing of an operation off.

As we move through the description of each of the joints, a mechanism for providing feedback for control purposes will be introduced.

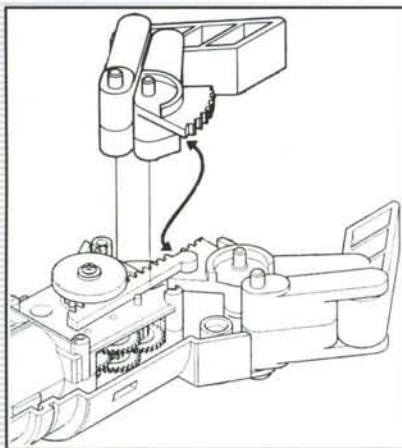


Figure 3. Gripper Design.

## Important Note:

To add feedback devices to the arm, will have to be in a disassembled state. It will be far easier to add instrumentation before it is assembled. In some cases, portions of the arm structure will be slightly modified. This will surely violate the manufacturer's warranty.

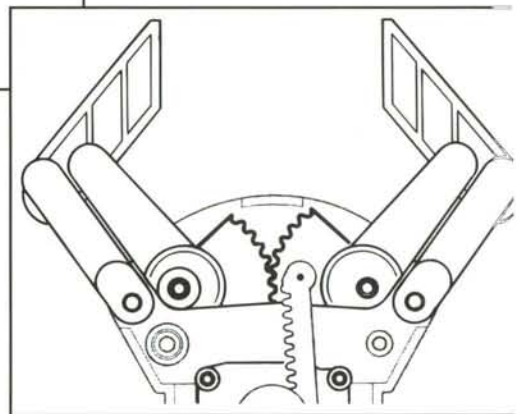


Figure 4. Finger Travel.

## Gripper Mechanical Design

The best place to start investigating the design of the OWI arm is at its finger tips (see Figure 3).

The gripper mechanism consists of what is known as a parallel jaw design. As the fingers open they remain in the same plane of reference, much like the jaws of a vise. As shown in the figure, the hand assembly consists of two fingers mechanically linked to a base structure. Figure 4 illustrates the orientation of a finger as it travels. Notice that the links constrain the finger's movement in a straight line.

Each of the fingers includes an integral non-slip rubber pad on its inside surface. This is where the grasped object is captured and the addition of the rubber surface increases its abilities by helping to eliminate slippage.

Movement is provided through the coupling of opposing gears and a rack-slide mechanism. There is an attached gear segment at the base of each finger (refer back to Figure 3). I describe this as a segment because it is not a complete circular gear. When the two finger gears are meshed together, they open and close simultaneously. One of the fingers includes an interface to a sliding rack gear. A gear directly attached to the hand motor powers the rack. As that

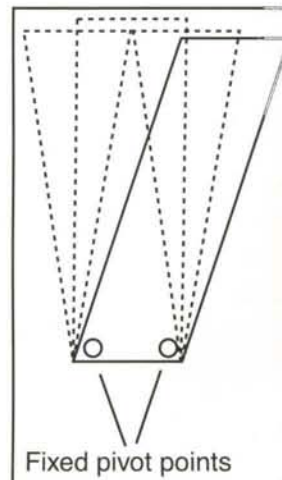


Figure 5. Hand Mechanism in Detail.

gear moves back and forth it pushes the fingers open and closed through a levered and geared rotating action. Study Figure 5 to get a full understanding of this mechanism.

## Instrumenting the Gripper

There are two places on the gripper where feedback mechanisms would come in handy. The first is to add some ability to sense when an object is between the fingers. That would give the controller a signal as to when to start closing the fingers for capture. The second sense to add is a determination of the position of the fingers in relation to each other. In other words, "How far open or closed are the fingers?"

A third sense that would be helpful is to determine when an object has been grasped. This can be accomplished directly by using sensitive contact switches on the surface of the fingers or indirectly by noticing that the fingers have stopped closing on their own without being commanded to stop. I chose the latter (indirect method) as this appeared to be a simple method to implement and it requires no modification to the arm itself.

There are three accepted methods for determining the position of moving mechanical components:

1. Contact switches
2. Optical reflectance or "break-beam" devices
3. Magnetic field detection

The obvious method of choice for determining when an object is located between the fingers is the optical break-beam device. Figure 6 illustrates the concept.

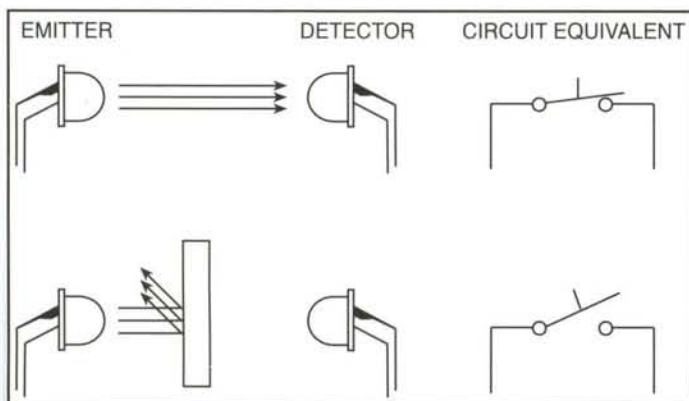


Figure 6. Infrared Break-Beam Optical Switch

An infrared emitter LED is placed within the surface of one finger. Directly opposite, an infrared detector (photo diode or phototransistor) is placed within the opposing finger. Aligned properly, the light from the emitter falls on the detector, which completes a circuit. This circuit is the equivalent of a switch that is normally closed. As the fingers open, they remain parallel due to their mechanical linkage. This maintains the alignment of the light beam and therefore the circuit remains intact. When a solid object is introduced between the fingers,

the beam is deflected. The light no longer activates the detector so it shuts off, opening the circuit. At that moment you have detection of the target object.

Depending on the thickness of the finger and the placement of the beam, you could be detecting only the very edge of the object. To close on the edge might result in a poor capture. The optimum method is to place two beams, one on each edge of the finger. This would determine a better grip point.

For this demonstration, I chose to add a single beam in the center of the finger at the tip. With smaller devices, a number of beams may be implemented.

## Object Detection

Begin adding the infrared devices by measuring the diameter of the emitter and detector components. These devices look like standard LEDs or transistors. For best results find a pair that are of the same size. You want the devices to point directly at each other, so the hole where the device is mounted to the finger should be drilled simultaneously through both of them.

Tape the fingers together as if they are in the closed position (see Figure 7). Drill a hole that matches the diameter of the components. Start from the outside of one finger and move through the junction of the two and clear through the remaining finger. Place the components into each hole from the outside of the finger so that the emitting or sensing end faces inward. Tape them into place until you have tested their operation. Later you can epoxy them to insure sturdiness.

Two wires attach to each device. These must be threaded through the finger joints and down into the base where everything is attached. Use thin flexible wiring. A simple schematic for operating the infrared beam is shown in Figure 8.

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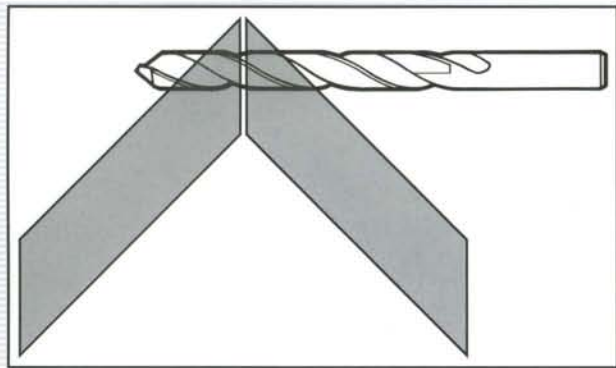


Figure 7. Drill the hole clear through both fingers.

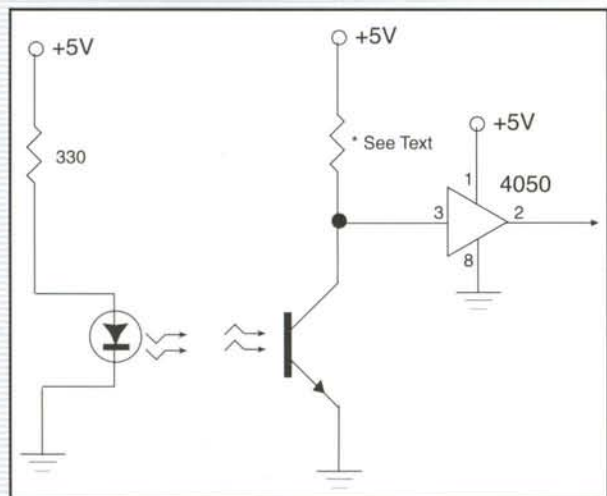


Figure 8. Simple IR Detector Schematic

In the circuit shown in Figure 8, the emitter on the left is biased using a 330  $\Omega$  resistor. This value may have to be modified depending on the type of infrared LED you choose. The resistor connected to the detector will have to be chosen experimentally. I found that a very large resistance ( $\sim 20 \text{ M}\Omega$ ) worked well.

## Finger Position Detection

A gear motor mounted within the hand structure opens the fingers. A small gear engages the rack, which moves finger gear segments. Somewhere along the path, we want to add a feedback mechanism. Examining the mechanisms involved, it becomes obvious that the teeth of the gear that drives the rack can provide feedback. Detecting their movement can act like a counter ticking off position units.

Of the available technologies, I found that a mechanical contact switch (also known as a micro switch or snap switch) activated by the main gear teeth of the gear that drives the rack would be the ideal method for this application. Although not as sophisticated as an optical circuit, it is simple and reliable for the duty we would place on the arm and very inexpensive. Figure 9 illustrates the concept.

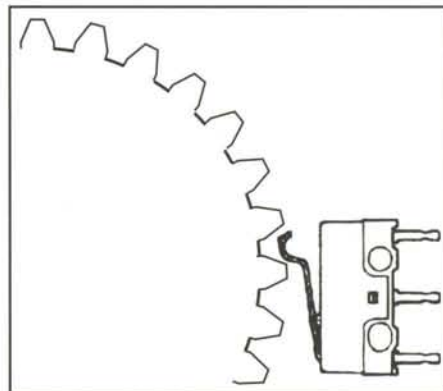


Figure 9. Switch Actuator Arm Engaging Gear Teeth

The integral lever of the snap switch travels along the gear, alternately making and breaking contact as the gear moves. An external controller would convert the switching into pulses that can be counted (Figure 10).

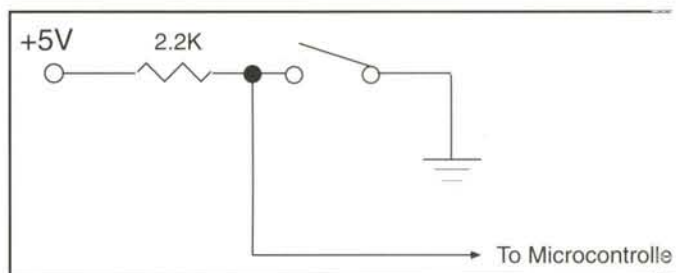


Figure 10. Interfacing a Snap Switch

The tricky part is the placement of the switch in relation to the gear and the shape of the lever. When you select a switch for the application try to get one with a "simulated roller lever". This is a metal lever that is bent to a rounded shape at the end. Standard roller lever switches are too big for the gear teeth. I found Omron D2F series switches to be ideal for this application. Straight lever versions of this switch are available through Digi-Key. You can bend the end of the lever into the proper shape using small needle nose pliers. Photo 1 shows the placement of the switch on the hand's motor.

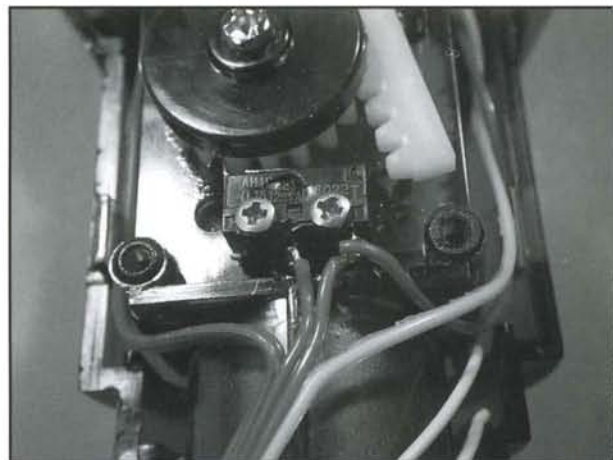


Photo 1. Contact Switch Engaging Final Drive Gear Of Finger Motor.

This method provides a somewhat medium resolution feedback. Due to the multitude of gears involved, removing power to the motor results in very little residual movement so the method is fairly accurate. Therefore, you can now command the gripper to open or close to a pre-determined position and stop.

## Wrist Mechanical Design

Of all the joints in the arm, the wrist (see Figure 11) proved to be the most troublesome. The mechanism where the wrist motor attaches to the hand (clutch plate) is very flimsy. The added weight of the sensors and the additional bundle of wires from the hand tend to make its operation somewhat unreliable. That is the main reason I suggest you use very thin flexible wire on the hand sensors.

The wrist mechanism consists of the gear motor directly engaging the clutch plate, which moves the hand assembly.

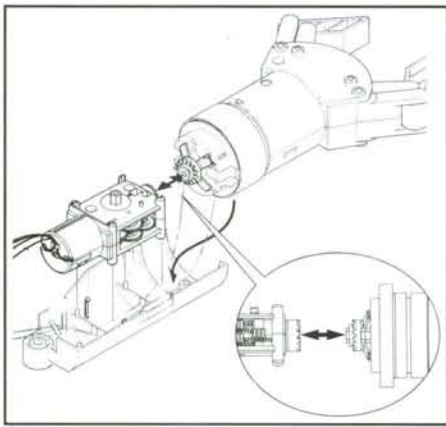


Figure 11.  
Wrist Mechanism Detail

## Instrumenting the Wrist

Due to the small space between the motor and the plate there is nowhere in that mechanism that a feedback sensor can be mounted. Luckily there are two shafts on each gear motor. The remaining shaft for this motor is a simple square plug that protrudes from the side of the motor with plenty of open space around for mounting sensors.

I decided to use the mechanical method on this joint as well. All that needs to be added is a small gear to the auxiliary motor shaft and a switch engaged with the gear. You can purchase small gears from a lot of sources. Lego manufactures several gear sizes. If you have Lego gears lying around your workshop use the small gear with 16 teeth.

Photo 2 illustrates a small Lego gear being added to the shaft. Some of the plastic from the middle of the gear must be removed to accommodate the shaft. After trimming, the gear is cemented in place.

Make sure you don't accidentally cement the shaft to the housing. Locating and wiring the switch completes the job.

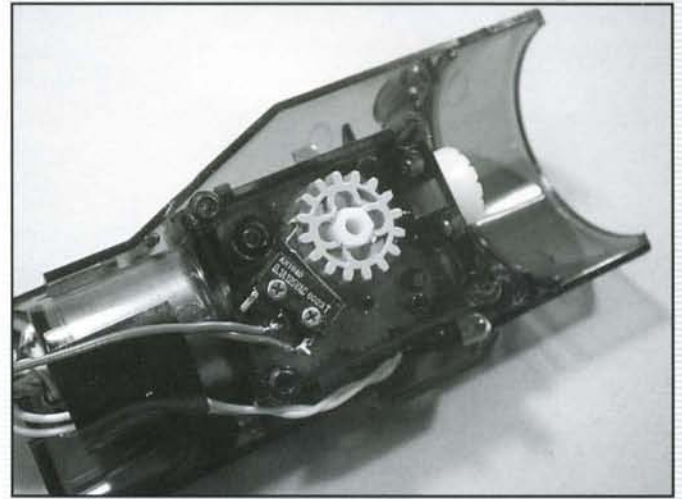


Photo 2. Contact Switch Engaging Lego Gear  
Added To Wrist Mechanism

## Elbow Mechanical Design

The elbow joint requires more torque because it must lift the hand and forearm assemblies. Mechanical advantage is added through an external large 45 tooth clutch gear (see Figure 12) that is fixed to the forearm. The gear motor engages a "Mediation Gear" that in-turn meshes with the large gear. The mediation gear acts as a translation between the gear motor and the structure. As the gear motor turns, the mediation gear turns the large clutch gear. This large gear is attached to the forearm and therefore moves the arm accordingly.

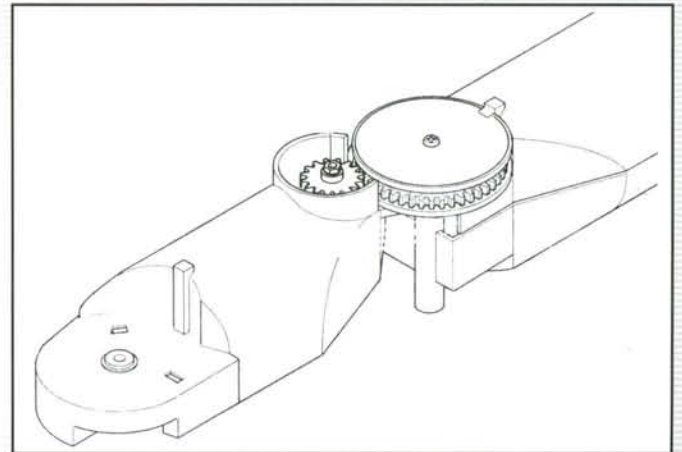


Figure 12. Elbow Mechanism Detail

## Instrumenting the Elbow

The mediation gear is almost fully enclosed in a plastic collar and is therefore inaccessible for feedback. The large gear seems to be the place to detect movement, however, its teeth are very close together and a stiff metal cover plate protects its edges.

After much deliberation I decided to use a variation of the wrist detection scheme. This variation adds a small gear to the top of the large clutch gear and mounts a mechanical switch on the large spacer that holds the clutch gear in place. The smaller gear moves when the large gear is engaged. The lever of the switch follows the teeth of the small gear and counts pulses (see Photo 3).

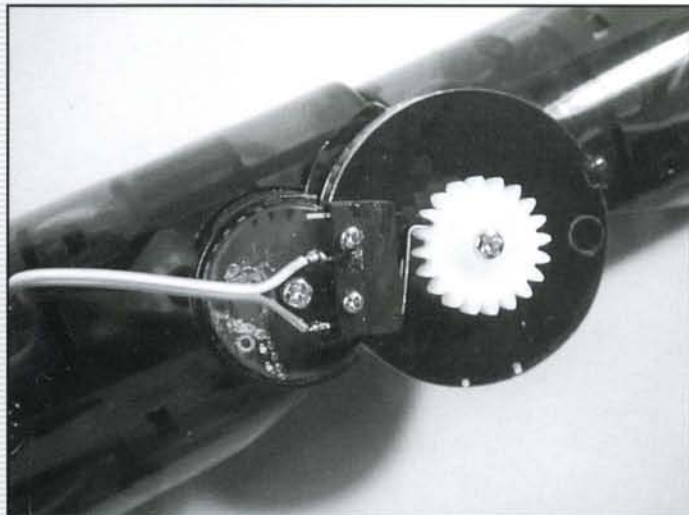


Photo 3. Contact Switch Engaging Small Gear Connected To Large Gear

As this switch is mounted on the outside of the arm, it is necessary to feed the wires back into the arm so they can travel to the base. This is accomplished by drilling a small hole in the upper arm.

### Shoulder Mechanical Design

The shoulder joint operates on the same principle as the elbow with some variation. Mechanical advantage is added again through an external large clutch gear (see Figure 13) that is fixed to the arm. The gear motor engages another mediation gear that in-turn meshes with the large gear. The large gear is attached to the arm and therefore moves it accordingly.

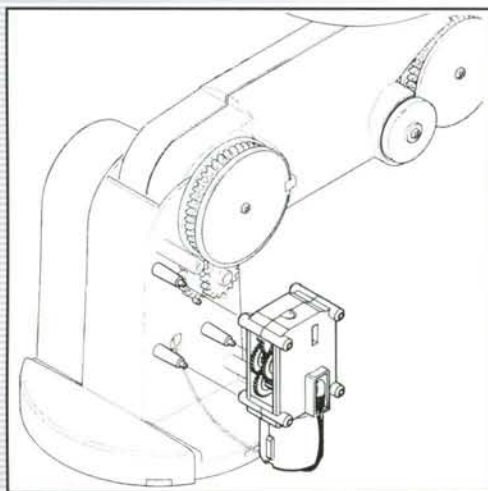


Figure 13. Shoulder Mechanism Detail

### Instrumenting the Shoulder

This time, the mediation gear is accessible for feedback. It is mounted inside a plastic cover in the base structure. There is plenty of room around the gear for mounting a mechanical switch (see Photo 4). The lever of the switch follows the teeth of the mediation gear and counts pulses.

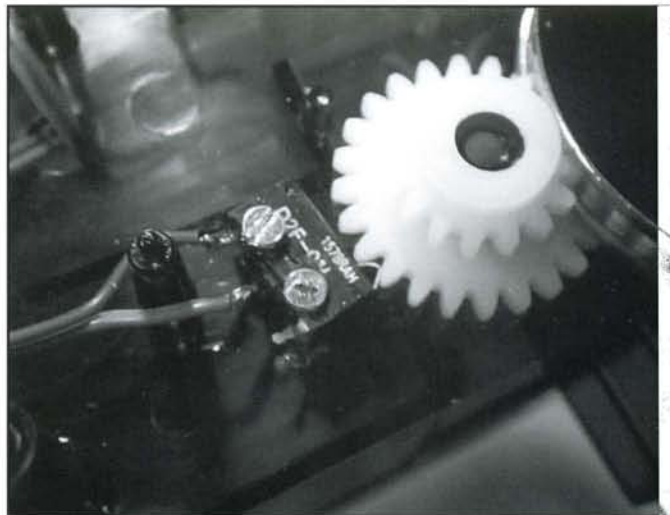


Photo 4. Contact Switch Engaging Shoulder Mediation Gear

### Base Mechanical Design

The base motor of the arm moves the entire structure, which pivots on an extrusion that rises through the center of the base structure. Because the structure is balanced on the pivot the motor requires little torque to move the assembly. The mechanism chosen to act as base drive operates the opposite of every other joint. In this case the motor actually travels around a stationary gear. Figure 14 illustrates the design. The large gear incorporates 74 teeth. The base motor is attached to the arm structure. Its powered gear meshes with the fixed gear that is connected to the base structure. When power is applied, the movable item (in this case the arm structure) rotates.

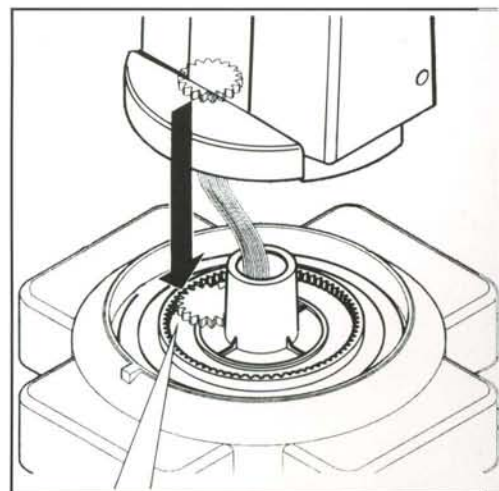


Figure 14. Base Mechanism Detail

## Instrumenting the Base

The easiest access to a gear that can be used for position sensing is the drive gear on the base motor. Unfortunately, when it is brought into contact with the base gear there is very little head clearance between the base and the pivoting structure. The snap switches we used for all other joints are approximately 0.25 in. thick. The clearance here is less than half that!

After much investigation I was able to find a sub miniature switch that does the job. It is also from Omron Corp. and is available through Digi-Key. The D2MQ line of switches are extremely thin units with an integral molded actuator lever.

The switch on the inside of the rotating base assembly is activated by the teeth of the motor gear. When positioning this switch be extremely careful. It is possible to have it turned so that it catches on the gear in one direction. If this happens, it will snap the lever right off the switch.

## Computer Control

When you have completed the instrumentation of the arm you end up with a bundle of wires that need termination. There are five contact closures and an optical switch to interface. Figure 15 depicts the electrical equivalent of our feedback sensors. The optical switch is not shown as this was covered earlier. A total of six input lines are needed to report the status of the arm to a microcontroller.

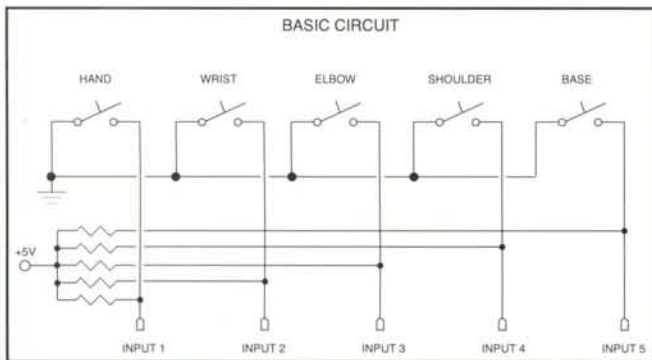
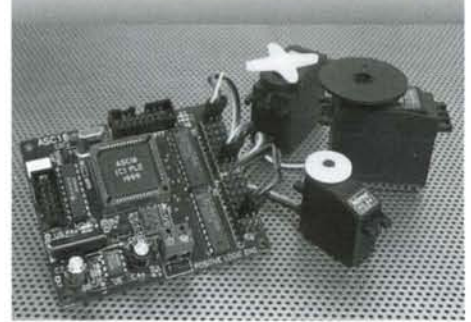


Figure 15. Arm Feedback Sensor Equivalent Circuit

Another article in this issue details an impressive computer-based interface kit for the motors. Also, OWI offers a very nice PC interface that connects between the arm trainer and your parallel port. Both provide complete software control of all five motors. The supplied software allows you to move the arm using programmed steps. They do not, however, include any provision for the feedback sensors we just installed.

In order to use the position switches you'll have to provide the computer with at least six inputs. A program needs to be designed that monitors each position sensor input. The circuit in Figure 15 presents five inputs that are normally at close to a +5 V level. When a sensor detects a gear tooth, its signal line is

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grounded, presenting a zero volt signal. When interfaced to a micro controller or PC these signals are detected as a 1 (when the voltage is close to +5 V) and a 0 when the switch is closed.

## Sensing Position

You need to design a program that accepts a position and then energizes the motor while monitoring the position sensor input. This program would count the number of 0s until it matched the position number. When the number is reached, the program turns off the motor.

The simplest way to do this is to determine beforehand how many 0s are produced as the joint travels from one extreme to the other. Do this by driving the joint to one extreme. Attach a counter circuit like that shown in Figure 16.

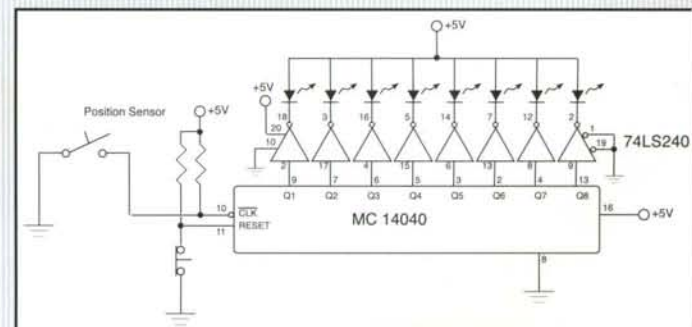


Figure 16. Simple Position Counter Circuit

Drive the arm to its other extreme and note the pattern of LEDs. The circuit in the figure has the ability of counting to 256 positions (8-bits). Each time the position switch presents a zero, the counter advances one count.

If a joint produces a count of 12, then moving it to its center position (exactly half way between extremes) would produce 6. Note the number of positions for each joint.

In your program, set up a counter for each joint. Enter the target position of the joint (the position you want the joint to reach) into the counter. Turn on the motor and watch the joint's position sense input. When it reads a zero (0), decrement the counter. Test the counter to see if it is at zero. When the counter decrements down to zero, the joint is in the desired position.

## Direction

Up to this point I haven't mentioned the direction that the motor is to turn. Obviously, if you stop the arm in the middle of its range, the next time you move it could be in either direction. This is where your program has to perform some logic. There are several clever methods for determining which direction to go from a given number. For this exercise, I'll just give you one idea.

Make the position of the arm an absolute number. One extreme will be zero and the other is the maximum count you measured.

You'll need three memory locations for each joint. Keep track of the current joint position, the desired joint position and the last memory location will serve as a position counter. Design the program to do the following:

1. At power-up, drive all joints to one extreme.
2. Clear all joint position memory locations.
3. When a position change is requested, subtract the current position from the desired position. If the result is a positive number, command the motor to turn in one direction. If the result is a negative number, command the motor to turn in the opposite direction.
4. Before energizing the motors, set the joint counter to the result. If the result is a negative number, just ignore the sign.
5. Energize the motor in the desired direction.
6. Monitor the joint position sensor input for a count pulse.
7. Decrement the joint counter for each detected pulse.
8. If the joint counter is zero, stop the motor. Otherwise, go to step 6.

## Detecting an Extreme

I did not include limit switch sensors for any of the joints. You could certainly place more micro switches to detect the joint extreme positions. There is a way in software to detect them as well.

As your program is monitoring the inputs for zeros it could include a timer. At a constant speed, position pulses will come at regular intervals. When there are no more pulses detected you haven't commanded the motor to stop and your internal counter is not at zero, you must be at a limit!

## Going Further

I am continuing to experiment with the OWI Arm Trainer. I'll keep abreast of its development and for more robot and control information, visit my website at <http://www.xantz.com>.

RS



*Mark has written several books and dozens of articles on experimental robotics. His new book is being introduced at the end of this year. He is currently a technical documentation manager for a large building automation company in the north east. More technical robotics and control tidbits may be found*

*at his website at [www.xantz.com](http://www.xantz.com). He welcomes comments at [mjr@xantz.com](mailto:mjr@xantz.com).*

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# Sensing & Locomotion

## Using the New OWI-007 with a Win95/98 Interface

by John Iovine

Here is a two module project using the OWI-007 robotic arm training kit and a PC interface kit available from Images Company (see resources at the end of this article.) Together these modules form a functional unit that permits you to experiment and program automation and animatronics into a fully controlled "wired" robotic arm.

One also has the option to control the arm interactively, in real time, using either a manual controller or the WIN95/98 program. The PC interface allows the use of a personal computer to program automation and animatronics into the robotic arm.

Once connected to the computer's printer port, the arm may be operated interactively, or it may be programmed from the computer.

Operating the arm interactively is easy. Simply click on any function button to command the robotic arm to perform that function. Click on the button a second time to end the function.

Programming automation is just as easy, just click on the "Program" button to enter the program mode. In this mode, the interface and robotic arm operate as described above. In addition, the program records each function and the time elapsed into a script file.

A script file can contain up to 99 separate functions, including pauses. An individual script file can be replayed up to 99 times by typing a number into a repeat box. Writing different script files allows one to experiment with computer-controlled automation and animatronics. The WIN95/98 program operation is described in more detail later.

The Windows program is included in the Images Company robotic arm interface kit or may be downloaded at no cost from the Internet at [www.imagesco.com](http://www.imagesco.com).

In addition to the Windows program, the arm can be operated from BASIC or QBASIC. A DOS-level program is included with the kit.

The DOS program only allows interactive functioning using the computer keyboard (see Basic code Listing, below).

Script file creation is *not* available in the DOS-level program. However, if one knows how to program in Basic, the arm may be programmed to perform a sequence of motions similar to a script file created in the Windows program. The motion sequence may be repeated, as is the case in many animatronics applications.

## Robotic Arm

The arm (Figure 1, page 7) moves in three axes. The elbow joint can move vertically (up or down) through a total arc of approximately 135 degrees. The shoulder joint moves the gripper (forward and back) through a total arc of 120-degrees. The arm can turn clockwise or counter-clockwise about the axis of the base approximately 350 degrees. The gripper portion of the robotic arm can grasp and release small objects up to two inches in diameter and rotate approximately 340 degrees at the wrist.

The OWI-007 Robotic Arm Trainer uses five small DC motors to produce motion. These motors are "wire" controlled, meaning that each DC motor, and hence each robotic function, is controlled by a wire (electrical power). Each of the five DC motors controls an arm function. The wire control makes it possible to build a controller unit for the arm that will respond to electrical signals. This simplifies the task of interfacing the robotic arm to a PC computer printer port.

The arm is made from lightweight plastic. Most of the stress bearing parts are also made of plastic. The DC motors used in the robotic arm are small, high rpm, low torque motors. To increase each motor's torque, it is connected to a gearbox. The motors and gearbox assemblies are an integral part of the construction of the robotic arm.

While the gearboxes increase the motors' torque, the robotic arm is not capable of lifting or moving a great amount of weight. The maximum recommended lifting capacity is 130 grams (4.6 ounces).



The robotic arm kit components have been thoughtfully laid out for kit builders (Figure 2).

The five DC motors come with the gearboxes already assembled and connected to the motors, (see Figure 3). This helps move the construction along. In a few hours, you have an operational robotic arm.



## Basic Motor Control

To understand the basic function of wire control, let's see how digital signals can control a single DC motor. Controlling a DC motor requires two complementary transistors. One transistor is a PNP type and the other a NPN type. Each transistor functions like a switch, controlling current to the motor.

The direction of the current controlled by each transistor is the opposite of the other, and since the direction of the current controls the direction the motor spins, clockwise (CW) or counter-clockwise (CCW), the active transistor controls the motor's direction.

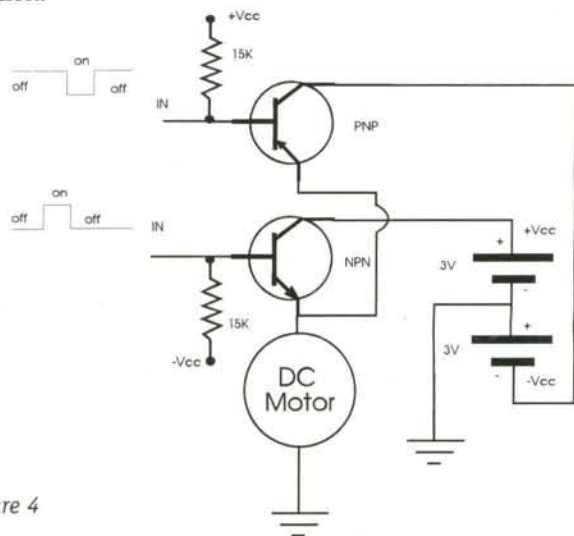


Figure 4

Figure 4 is a test circuit that you may build before building the robotic arm interface. Notice if both transistors are turned on the motor is off. Only one transistor (per motor) should be turned on at a time. If two transistors to the same motor were accidentally turned on at the same time, it would be the equivalent of creating a short circuit. On the robot arm, each motor is controlled by two transistors on the interface in a similar manner.

## PC Interface Construction

The PC interface schematic is shown in Figure 5. The Printed Circuit Board (PCB) pattern for the circuit is illustrated in Figures 6 and 7, and parts placement on the board is shown in Figure 8.

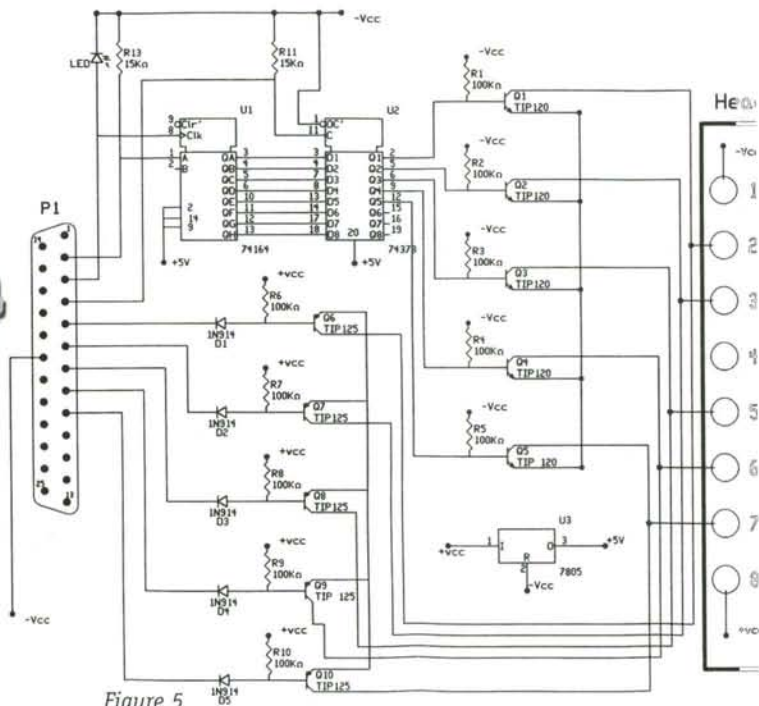


Figure 5

To begin construction, first identify the component side of the PCB. The component side has the white line drawings of the resistors, transistors, diodes, IC's and DB-25 connector. All components are mounted on the component side.

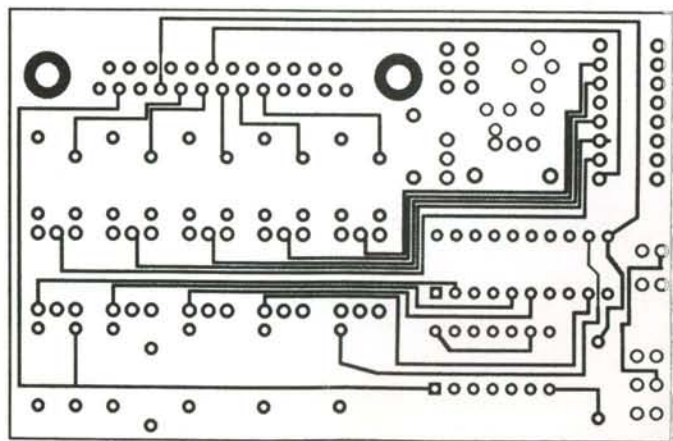


Figure 6. Top Copper

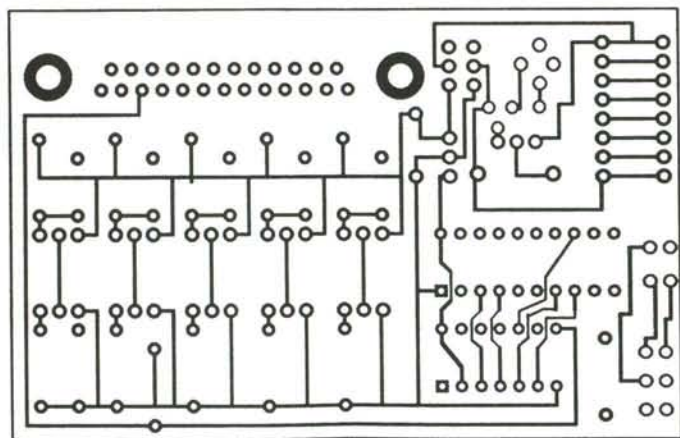


Figure 7. Bottom Copper (below)

In general, after soldering a component to the board, clip away any excess wire from the underside of the PCB. It's a good idea to follow the sequence for mounting the components. Begin by mounting the 100 kΩ resistors (color bands brown, black, yellow, gold, or silver) labeled R1 through R10.

Next, mount the five diodes D1 to D5, making sure the black band on the diode faces toward the DB-25 connector, as shown on the white line component drawing.

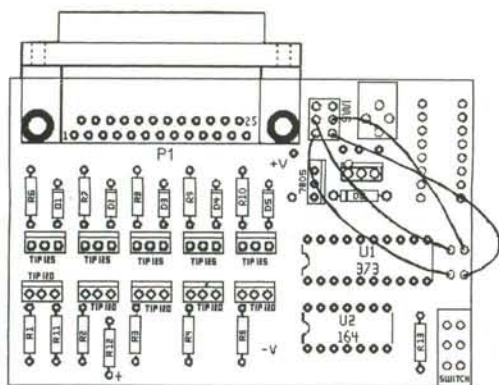


Figure 8. Parts Placement

Next, mount the 15 kΩ resistors (color bands brown, green, orange, gold or silver) R11 and R13. Mount the red LED in the R12 position. The positive lead of the LED is mounted in the + label R12 hole. Then mount the 14 and 20 pin sockets in the U1 and U2 positions. Mount and solder the DB-25 right angle connector. Do not force the DB-25 pins through the board, it is a precision fit. If necessary, gently rock the connector in, making sure not to bend any pins.

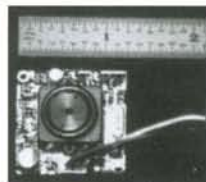
Mount the slide switch and the 7805 voltage regulator. Cut and solder four wires above the switch, as shown in Figure 8. Take care to keep the wire orientation as shown. Mount and solder the TIP120 and TIP125 transistors. Finish the project by mounting the eight-position header and three-inch connection cable. The header is mounted so the longer leads face upward. Insert the two integrated circuits, the 74LS373 and 74LS164, into their respective IC sockets. Be sure to orient the indentation on the

# Quality Kits



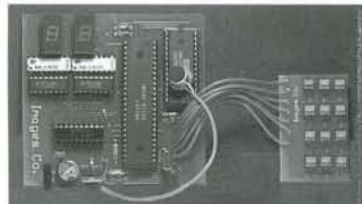
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topside of the chip with the indentation on the white line drawing. You may notice that there are places for additional components. This is for an additional AC Adapter.

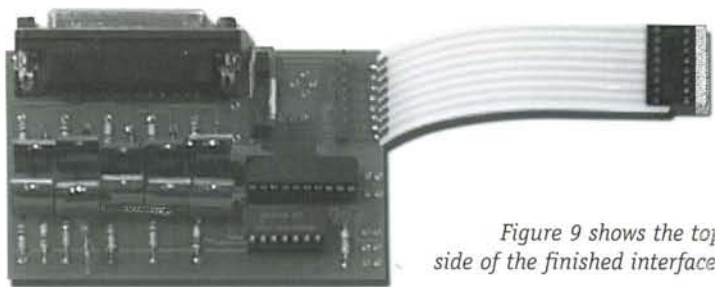


Figure 9 shows the top side of the finished interface

## How the Interface Works

The arm contains five DC motors. We need ten Input/Output (I/O) lines to control each motor and direction. The parallel (printer) port on the IBM PC and compatibles has only eight I/O lines. To increase I/O lines the robotic arm interface incorporates a Serial In Parallel Out (SIPO) integrated circuit, the 74LS164. By using just two lines off the parallel port, lines D0 and D1, to send serial information to the chip we can add eight I/O lines. Although eight I/O lines are available off the SIPO, the interface requires using just five of those I/O lines.

When serial information is transmitted into the 74LS164 SIPO chip, the parallel output of the chip shifts in response. If these outputs were directly connected to the transistors, the arm functions would switch on and off as the serial information clocked in. Obviously, that would not be a suitable situation. To prevent

this from happening, a second chip is added to the interface, the 74LS373 octal latch.

The 74LS373 octal latch has eight input lines and eight output lines. Binary information placed on the input lines are transmitted (made transparent) to the output lines when the chip is enabled. When the chip is not enabled, the information on the output lines is latched. When latched, the binary information on the input lines has no effect on the status of the output lines.

When all serial information has been transmitted into the octal latch, it is enabled via parallel port pin D2. This allows the parallel information from the SIPO to be transmitted to the output lines of the latch. The output lines from the latch switches the TIP120 transistors on and off, thereby controlling the robotic arm functions. The process is repeated for each new command to the arm.

Parallel Port lines D3 through D7 control the TIP125 transistors directly.

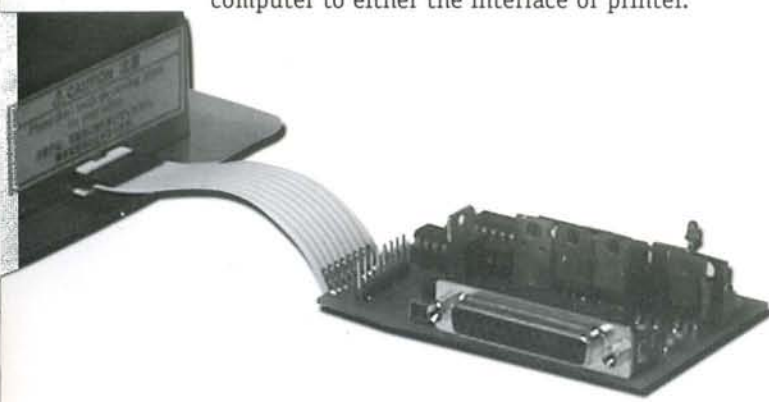
## Connecting the Interface to Robotic Arm

The arm uses a single 6-volt power supply consisting of four "D" cell batteries in the base. The PC interface takes power from the arm's 6-volt power supply. The power supply is used like a bi-polar +/- 3-volt power supply. Power is tapped from the 8-conductor Molex connector to the arm base (see schematic at Figure 5).

Connect the interface to the arm using the 3-inch long 8-conductor Molex cable. The Molex cable is inserted into the connector on the base of the robotic arm (see Figure 10). The Molex connector must be properly and firmly seated. To connect the interface to the computer's printer port use the 6 foot DB-25 cable supplied with the kit. One end of the cable connects to the computer's printer port. The other end connects to the DB-25 connector on the interface board.

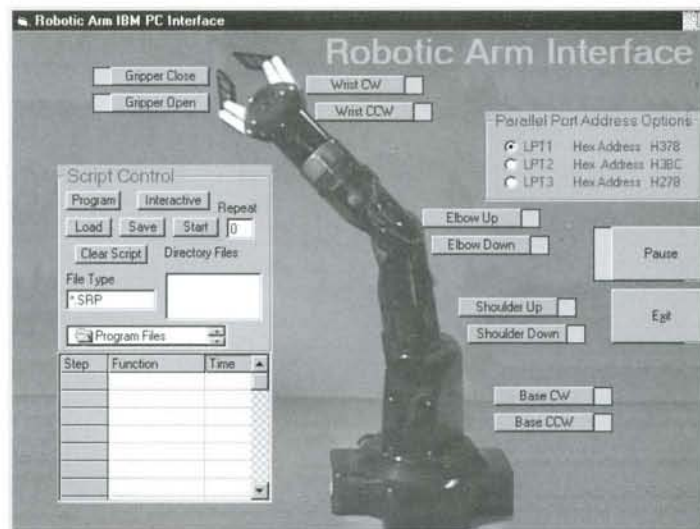
In most cases, the printer port is also used for the printer. To alleviate switching cables back and forth whenever you want to use the robotic arm, purchase an A/B data switch (DB-25) box.

Connect the robotic arm interface printer to the A side and the printer to the B side. Now you can use the switch to connect the computer to either the interface or printer.



## Installing the WIN 95 Program

Insert the 3.5 in. diskette labeled "Disk 1" into the computer floppy drive and run the set up program (setup.exe). The setup program creates a directory named "Images" on the computer hard drive and the needed files are copied into this directory. An "Images" icon is created on the Start Menu. To run the program, click on this icon.



## Using the WIN 95 Program

Connect the computer's printer port to the interface using the 6 foot DB-25 cable. Connect the interface to the base of the robotic arm. The interface should be 'off' for the time being. If you turn the interface on at this point, the existing information (status left on the printer port may cause the robotic arm to begin performing a function.

Start the program by double clicking the *Images* icon in the start menu. The program's opening screen is shown in Figure 11.

When the program is running, the red LED on the interface should be blinking. The interface does not have to be turned on for the LED to blink. How fast the LED blinks depends on the speed of the processor in your computer. The blinking light from the LED may be very dim; you may need to block some room light to see it by cupping your hands around the LED.

If the LED is not blinking, the program is probably set to the wrong printer port address (LPT Port). To set the interface to a different printer port address, go to the Printer Port Options box on the upper right hand corner of the screen. Click a different option. Whichever port setting option causes the LED to start blinking is the correct printer port address.

With the LED blinking, click on the pause button and then turn the interface on. Clicking on any function button causes the robotic arm to perform that function. Clicking on the button a second time stops that function. Using the function buttons to control the arm in this manner is called the interactive mode.

## Creating Script Files

To program motion and automation into the robotic arm we use script files. The script file contains a list of timed instructions that control the robotic arm function. Creating script files is simple. To create a script file, click on the program button. This puts you in the "programming" script writing mode. Clicking on a function button will start the robotic arm function as before.

In addition, the function information is entered into the yellow script table on the lower left of the screen. The step number is placed in the left column, beginning with Step 1 and increments with each new function. The function name is entered in the middle column. When the function button is clicked a second time, the function stops and the elapsed time from start to stop is entered into the third column. The time elapse is incremented in quarter seconds.

Continuing in this manner, a user may program up to 99 functions, including timed pauses, into a script file. Script files may be save to, and loaded from, the local directory. Script files may be set to replay up to 99 times by typing a number in the repeat box and hitting start.

To stop writing into a script file, click on the interactive button. This puts the computer back into the interactive mode.

## Animatronics

Script files may be used for computer automation or for "animatronics." In animatronics the underlying mechanical robotic system is usually hidden from sight. The coverings vary from humans (whole or partial) to aliens, animals, plants, minerals or anything else you may choose to animate.

## Limitations

If you were performing automation or animatronics on a professional level it would be required to position the robot exactly, to hit its mark, so to speak, 100 percent of the time.

You will notice that as a sequence (script file) is continually repeated the position of the arm will drift. There are a number of reasons for this. As the battery-supplied power to the robotic arm becomes depleted, the reduction in electric power delivered to the DC motors reduces their torque and speed. So during a timed function, the motors will not move as far or lift as much with old batteries as they would with fresh batteries.

Even with a regulated power supply, how many times a DC motor shaft spins in a given length of time is neither counted nor controlled. So the number of turns the motor spins in each timed sequence will vary by a small percentage. This also causes the position of the arm to drift. If that isn't enough, the gears used in all the motor gearboxes have a certain amount of slop (or play) that isn't taken into account.

Considering these factors goes a long way toward explaining why the position of the arm repeatedly performing a script file will drift over time.

## Finding Home

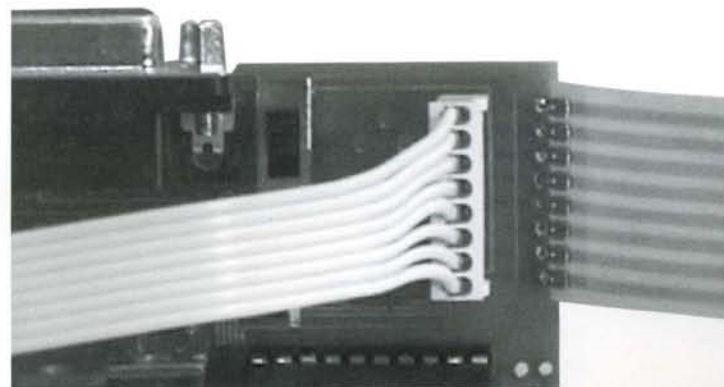
To enhance this project, positional feedback from the arm could be implemented so the computer could determine absolute position of the arm. With basic positional feedback, the arm can be located in precisely the same position every time at the beginning of a script file (sequence) run.

One can take many approaches. A basic method uses limit switches to find a "HOME" or starting position. The limit switches determine when the arm reaches one absolute or "HOME" position. To accomplish this, a series of limit switches (momentary contact lever switches) will close when the arm reaches its limit of travel in that particular direction.

For instance, one limit switch would be mounted to the base. This switch would close only when the robotic arm was turned completely in a CW direction to its stop. Other limit switches would be mounted on the shoulder and elbow. They would close when the respective joint was fully extended. Another switch, mounted to the wrist, would close when the wrist was rotated to the furthest CW position. The last switch, mounted to the gripper, would close when the gripper is fully opened. To reset the arm to its "HOME" position each function is activated in the direction of travel needed to close that limit switch until it actually closed. After all the functions, and thus the arm, are in the "HOME" position, the computer would know the absolute position of the arm.

Knowing that the drift occurring during one run of the script is probably minimal, once "HOME" we can start or replay a script and the robotic arm will hit all of its marks. When the script is finished, and the arm has been reset to "HOME," the script can be replayed with reliable accuracy.

Sometimes a home position does not give enough feedback to perform certain operations. For instances, picking up an egg without crushing the shell. For these applications more sophisticated



methods of feedback need to be employed. Signals from transducers are processed using Analog to Digital converters (A/D). The processed signals are used to determine factors such as position, pressure, speed, torque etc.

A simple example will illustrate. Imagine mounting a small linear potentiometer on the gripper section. The potentiometer is mounted so that when the gripper opens or closes the potentiometer slider is moved back and forth. Thus, as the gripper opens and closes, the resistance of the potentiometer varies. Once calibrated, the resistance could accurately tell how far the gripper closed (or opened).

Feedback systems add another layer of complexity and cost to the system. The manual control system can always be used to override and reposition the robotic arm as a script is running.

## Connecting Manual Control to Interface

After the interface is running properly, connect the manual control to the interface using the 8-pin header. Orient the manual control Molex connector to the 8-pin interface header as shown in Figure 12. Press the connector firmly onto the header to seat. The robotic arm can be controlled manually at any time, even if the interface is connected to the computer.

## DOS Level Keyboard Program

The keyboard program is at the DOS level. This allows you to control the arm in real time (interactively), using the keyboard. The following keys perform the following functions:

Key / Function	Key / Function
"U" = Up	"D" = Down
"L" = Left	"R" = Right
"G" = Grip	"H" = Release
"S" = Stop	"Q" = Quit

## Troubleshooting

The construction pamphlet that comes with the interfacing kit has an extensive troubleshooting guide for dealing with construction errors and printer driver conflicts.

RS

## Robotic Arm Interface Kit Parts List

Qty	Item
5	TIP120 NPN Transistors
5	TIP125 PNP Transistors
1	74164 Serial to Parallel IC
1	74LS373 Octal Latch
1	Red LED
5	1N914 Diodes
1	8 Position Molex Header
1	8 Position 3 in.-long Molex Cable
1	PDT PC Mounted Switch
1	B25 RT Angled PC Mounted Connector
1	B25 M-M 6 foot cable
1	PCB Board
10	100 k $\Omega$ 0.25 watt resistors
3	15 k $\Omega$ 0.25 watt resistors
1	7805 Voltage Regulator

## Resources

### OWI-007 Robotic Arm Trainer

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### Robotic Arm Interface Kit

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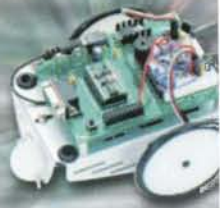
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# BUILDING AND PROGRAMMING A SMALL MOBILE ROBOT

The first article of an educational series.



by Chuck Schoeffler, PhD., Russ Miller, and Ken Gracey

*Building and programming a simple robot is an ideal way to learn how microcontrollers interface with machinery. It's an effective method for novices of all ages to see and hear outputs in addition to being able to measure them with a multimeter or oscilloscope. The light, sound, and movement of your robot will capture your imagination. That is our intent – to fire up your interest and imagination as you proceed through these projects.*

This series of articles is about several interesting and informative projects you can do with a simple mobile robot. To illustrate the concepts we used the Board of Education Robot, the Boe-Bot, a mobile robot built by mounting the Parallax Board of Education and BASIC Stamp II on a chassis equipped with drive train, wheels, and eventually sensors. You can assemble a Stamp-based servo driven platform following the schematics shown in these articles and learn to build and program a small mobile robot of your own.

Through these articles, we will build a simple robot to experiment with sensors, programming, and electronics. At a glance, the series will cover the following projects:

- Article #1: Building the Boe-Bot – Construction process and drawings for building your small mobile robot. Brief introduction to the BASIC Stamp II.
- Article #2: BASIC Programming – Program the robot to follow a pre-entered path using subroutines and electrically erasable programmable read only memory (EEPROM) storage. Use a piezo speaker for feedback.
- Article #3: Sensors – Use a photoresistor and Analog/Digital (A/D) converter or resistor/capacitor circuit to sense and follow light.
- Article #4: Infrared (IR) Control – Add IR module and decode signals from an infrared remote controller.
- Article #5: Advanced Projects – Build an oscillator circuit using the same IR module for proximity sensing.

It is not necessary to buy a Board of Education; you can easily rig up a breadboard for the job. Serial port programming connections to the BASIC Stamp are shown in the BASIC Stamp Manual Version 1.9, available as a free download from [www.parallaxinc.com](http://www.parallaxinc.com). Measurements are provided for the robot chassis so you can build your own from metal, plastic or even wood.

## About the BASIC Stamp II Microcontroller

These experiments will use the BASIC Stamp II. The BASIC Stamp II (BS2-IC) is an inexpensive microcontroller (less than \$50 US) with a built-in BASIC interpreter. If you haven't already seen the BASIC Stamp II, you can download the manual, datasheets, and DOS/Windows editors from the Parallax web site. Here are some of the essential features of the BASIC Stamp II:

- Small size, like a postage stamp.
- BASIC interpreter firmware is built into the PIC16C57 microcontroller.
- BASIC program storage in non-volatile EEPROM. When power is applied, the program executes. BASIC Stamps can be programmed at any time by temporarily connecting them to a PC running a simple host program. Type in a new program, press a key and the program is downloaded.
- Sixteen general-purpose input/output (I/O) pins that can be interfaced to switches, digital circuits, and even drive small loads.

## Project Platform: Board of Education

The Board of Education will hold your BS2-IC and serve as your project area for circuits. The board has a DB9 connector for BS2-IC programming and serial communication during run-time. The integrated circuit's (IC's) 16 I/O pins, Vdd (+5 V) and Vss (Ground) connections are ported to the perimeter of the 2 x 1 3/8 in. breadboard where you will add sensors to your robot. The traces on the top of the board show the connections between the BS2-IC and the breadboard. Figure 1 shows the Board of Education schematic. The Boe-Bot was designed after the Board of Education, and the single power supply will be used for both the BASIC Stamp and motors.

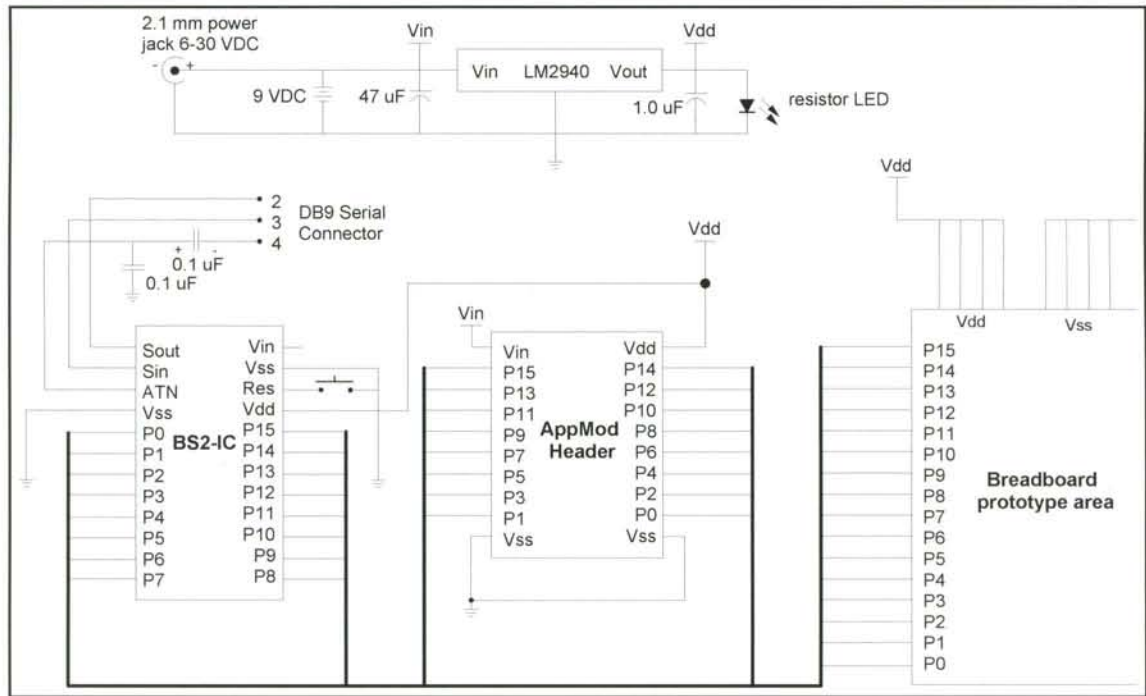


Figure 1:  
Board of  
Education  
Schematic

## Chassis for your Robot

The design concept of mounting a Board of Education on a robot chassis as an experimental tool comes from Chuck Schoeffler, PhD., University of Idaho. Dr. Schoeffler's first and second approaches are shown in Figure 2. Although he uses these designs in his classes at UI, a production version was required to accommodate the needs of educators at high schools and colleges across the country. Based on Dr. Schoeffler's idea Parallax developed the aluminum chassis shown in Figures 3, 4, 5, and 6. Whatever form your chassis takes, make sure that it accommodates two servos for drivetrain, a battery pack for four AAs, and a prototyping area for project development. If you would like to do the hands-on chassis work yourself, fully dimensioned drawings are provided as a free download. These drawings are in Autocad \*.dwg and \*.dxf and may be edited for your own customization (there's also a PDF version in case you can't access ACAD formats). These drawings are available from <http://www.stampsinclass.com>.

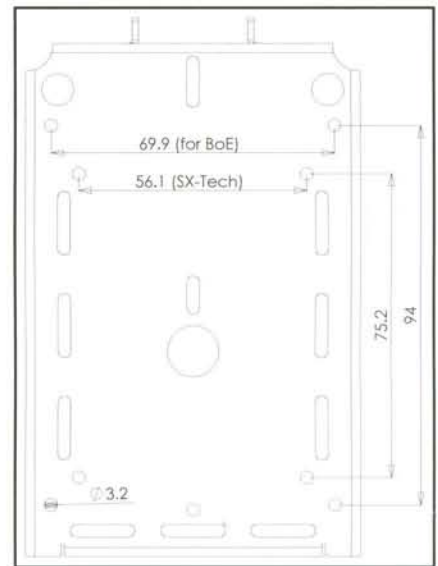


Figure 3: Top Dimensions

Figure 2: Dr. Schoeffler's first two robots had different forms but both used a BASIC Stamp.

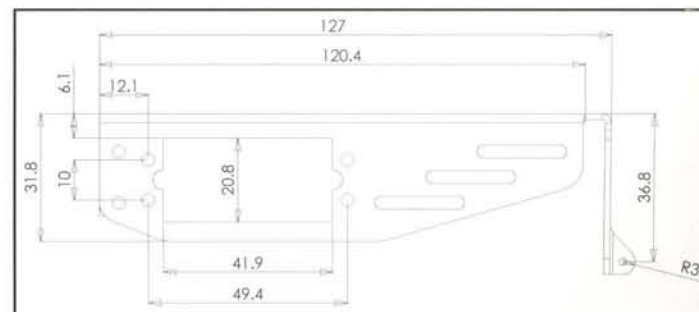
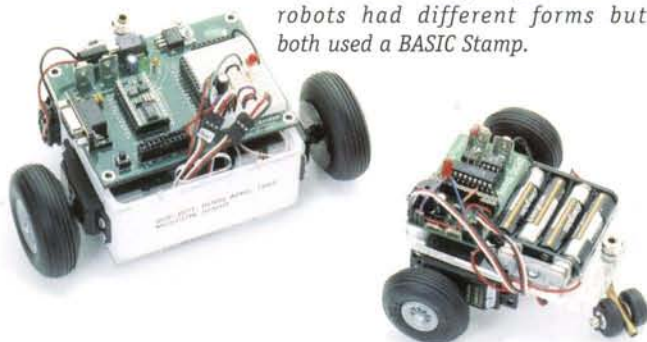


Figure 4: Side Dimensions

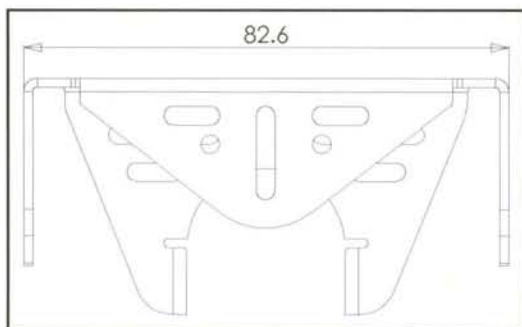


Figure 5: Front Dimensions

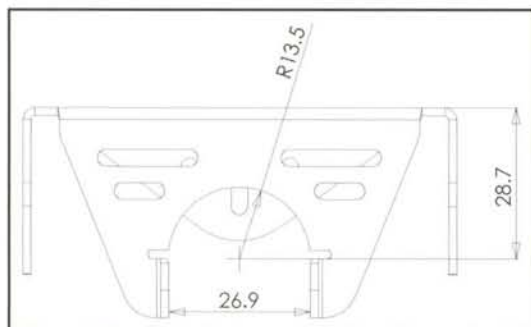


Figure 6: Back Dimensions

#### PARTS LIST

- One BASIC Stamp II (BS2-IC)
- One Board of Education
- One Boe-Bot chassis (either purchased or built)
- Two Futaba FP-S148 servos
- Two Plastic wheels
- Two O-ring tires
- One Polyethylene ball wheel
- One Cotter pin to hold wheel on chassis
- Eight Machine screws 4/40 3/8 in.
- Ten Nylon insert locking nuts 4/40
- Four 1/2 in. standoffs
- Eight Flathead screws 4/40 3/8 in.
- Two Grommet 3/8 in. inner diameter
- One AA four battery pack holder
- Two 10 kΩ resistors
- One 10V or 16V 3300μf capacitor

Figure 7: Boe-Bot chassis parts

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## Assembling your Small Mobile Robot

This is an illustrative design; substitute parts as you desire if you are building your own chassis. For the commercially available approach you'll need the chassis parts (Boe-Bot Full Kit) shown in Figure 7, which also includes a BASIC Stamp II, and a Board of Education.

Boe-Bot construction requires a small Phillips screwdriver, 1/4 in. box end wrench or pliers, and diagonal cutters. Constructing the robot is divided into five steps:

- Step #1: Mechanical modification of the Futaba FP-S148 servos to provide continuous rotation and testing them for use as a robot chassis drivetrain,
- Step #2: Mounting the servos on the robotics platform and attaching the wheels,
- Step #3: Attaching the tail wheel and battery holder,
- Step #4: Mounting the Board of Education and BASIC Stamp II on the completed platform and connecting the servos to the BASIC Stamp, and
- Step #5: Programming your robot with some sample source code to verify that it works.

## Step #1: Servo Modification and Testing

### Servo Modification

The servo modification process was described in detail in the November 1998 RS&T article by Karl Lunt "Motorize your Small Bot by Modifying the Futaba Servomotor FP-S148." Therefore, this is only an abbreviated refresher. When modified, the FP-S148s become low cost geared motors that provide the locomotion to move your robot. These servos respond to a pulse width modulation signal (PWM) that you send using the BASIC Stamp.

Modifying the Futaba FP-S148 servo takes only a few minutes (or less, if you've done it before). The servo has a round control horn attached to the main output shaft and secured in place with a Phillips screw. Turn the servo horn with your fingers clockwise and counter-clockwise until the shaft stops to see how the servo operates. We will modify it so that the horn will turn continuously.

The modification process starts by taking the screw out of the horn and removing the horn. The gear shaft has splines, so you will have to apply upward pressure and then wiggle it off. Look at the bottom of the servo and you'll see four Phillips head screws. Remove these screws and lay the top case off to the side. The servo should now be in two pieces (see Figure 8).

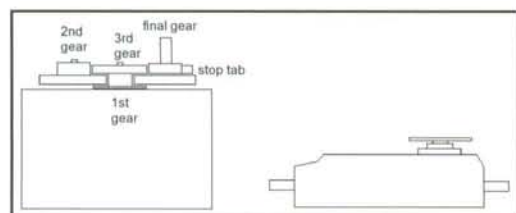


Figure 8:  
Open Futaba  
FP-S148 Servo

You won't need to do any soldering unless you break a wire.

The final gear is the one you are going to modify. You'll need to remove the third gear in order to access the final gear. Looking at the top of the final gear you'll see a plastic stop tab that we need to remove to allow the servo to turn completely around. Remove the stop tab with diagonal cutters, but don't cut into the gear teeth. The tab is shown in Figure 9.



Figure 9: Removing the Futaba  
FP-S148 Stop Tab

Turn the final gear over and look at the bottom. You will see a metal ring pressed into the plastic, and you need to pry that out with a small screwdriver, your fingernail or a paper clip. Remove the potentiometer drive plate. Insert the metal ring back into the main gear. Figure 10 shows the bottom of the main gear. Don't reassemble your servo once you've finished this task because we need to calibrate it using the BASIC Stamp.

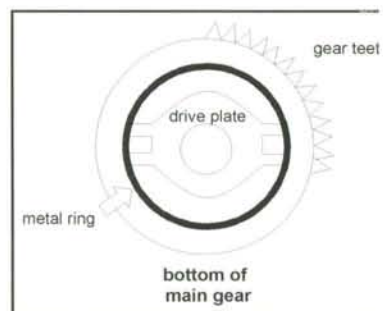


Figure 10: Removing the  
Potentiometer Drive Plate

### Servo Testing and Calibration

At this point, your servo is disassembled and the final gear removed to expose a metal post that is part of the potentiometer. We will be changing the position of the potentiometer to complete the modification for continuous rotation. This step makes sense if you have a brief understanding of how the servo's internal electronics operate.

A servo is a classic example of a closed-loop feedback system. It has an internal potentiometer (the small metal shaft underneath the final gear) that is coupled to the output gear. Its resistance is proportional to the position of the servo's output shaft (0° to 180° before modification). This resistance is compared to the BASIC Stamp's command to generate an error signal when the commanded position isn't the same as the current position. If the head had been at 180° and the commanded position was 90°, an error signal of opposite polarity would have been generated and the motor would have turned in the original direction to bring the head 'back' to 90°. The current position is 'fed-back' to the servo's control system in a loop to maintain a zero error signal. Therefore, the value of the error signal is determined by the pulse width command sent by the BASIC Stamp and the physical position of the potentiometer.

The servo's internal potentiometer must be rotated to be centered according to a signal it expects to receive from the BASIC Stamp. This is done by connecting the servos to your BASIC Stamp and Board of Education as shown in Figure 11. This schematic shows the servo case installed for convenience, though it should

still be removed at this point. Servos have three wires leading from the base: power, ground and control. The control lead is used to send the positioning signal - the one connected to the BASIC Stamp I/O pin. If you are using the Board of Education's power supply to drive the servos, you will need a 3300  $\mu$ F capacitor between power and ground. If you already have a Board of Education and it has a 7805 regulator, contact Parallax for a free LM2940 Regulator Upgrade Kit by asking for part number 28151. This low-dropout regulator allows the power supply to be shared between the servos and BASIC Stamp provided you install the 3300  $\mu$ F capacitor.

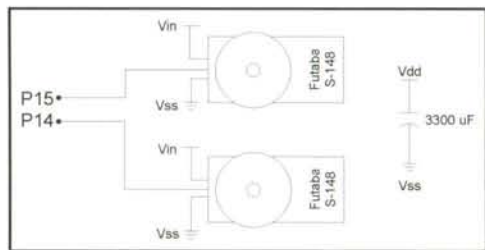


Figure 11: Schematic to Center a Servo and operate your Boe-Bot for Simple Movement

To program the BASIC Stamp you can download the free Windows 95/98/NT 4.0 interface from <http://www.parallaxinc.com>, and connect the Board of Education to your computer using a serial cable. To tune the potentiometer download the following code into your BASIC Stamp:

```
'Program for servo calibration with BS-2
'C. Schoeffler, University of Idaho
center:          'name for routine
pulsout 15,750   '1.5 ms pulse to the servo on P15
pause 20        'delay between 20 ms and 50 ms
goto center     'repeat until calibrated
```

While the BASIC Stamp is executing this code and the servomotor is running, turn the potentiometer shaft until it stops moving on its own. Change the pulsout 15,750 to read pulsout 14,750. Make the same potentiometer changes to the second servo. So what have you done?

Servos are controlled using a system called Pulse Width Modulation (PWM). In order to understand this, you need to understand the terms "milliseconds" (ms) and "microseconds" ( $\mu$ s). A ms is 1/1000th of a second; or put another way, there are 1000 ms in every second. A  $\mu$ s is 1/1,000,000th of a second, therefore there



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are 1 million  $\mu$ s in each second. Servo manufacturers usually specify pulse-widths in  $\mu$ s. The servo's electronics work in 20 ms blocks (50 of them every second). For each 20 ms block, the servo needs to receive a positive-going pulse with period (width in ms) that tells it where to position the head (output shaft).

The period of the pulse you sent was 1.5 milliseconds. When you rotated the shaft back and forth, the servo's potentiometer was comparing the pulsout value of 750 to what it expected to receive for the potentiometer's center position after modification. This is actually 1.5 milliseconds because the pulsout command is in units of 2 ms, thus  $750 \times 2 = 1500 \mu$ s or 1.5 ms. You rotated the shaft until the two values were equal and the servo gears stopped moving.

Check the servo again before reassembling to insure the servo stopped at the position you commanded with the test program. The servo case parts should go back together smoothly and you should just barely be able to see where the case parts join.

## Step #2: Mounting Servos and Wheels on the Robot Platform

Mount the servos in the chassis. The servo spline should be closest to the center of the Board of Education. This will allow a tight turning radius. The wheels will fit exactly onto the servo spline. Once this is finished you can slide the rubber tires over the wheels.

### Step #3: Install Tail Wheel and Battery Holder

Mount the tail wheel using a cotter pin. The battery holder is attached using flathead screws and nut.

### Step #4: Mounting the Board of Education and Connecting the Servos to the Chassis

Mount the Board of Education on the robot chassis base with four 4/40 machine screws and standoffs. The breadboard should be closest to the front of the chassis, centered directly in between the two wheels. This will allow sensors to be mounted in a position where they can respond to the environment in front of the robot.

Once this is done, connect the servos as shown in Figure 11. You may also put a 10 k $\Omega$  resistor between the power and ground of each servo. This resistor prevents short servo movements during "timeouts" when the robot is in a sitting stage and the servos are being pulsed with 750. This will be more obvious when we start programming. A finished Boe-Bot is shown in Figure 12.

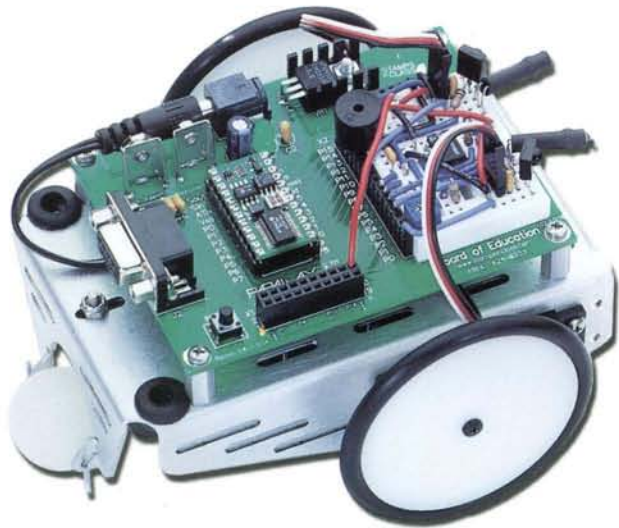


Figure 12: Complete Boe-Bot. This model includes the infrared circuit we will use in a future experiment.

### Step #5: Programming your Small Robot for a Basic Movement Pattern

If construction went okay, the robot is now ready to be programmed for a basic movement pattern. Connect the Board of Education to your computer's serial port and load the following code in your BASIC Stamp using the Win95/98/NT4.0 editor:

```
'Test program for the Boe-Bot
x var word
test:
  pause 2000
  gosub forward
  pause 500
  gosub back
  pause 500
  gosub left
  pause 500
  gosub forward
  pause 500
  gosub right
end

forward:
  for x=1 to 100
    pulsout 14,650
    pulsout 15,850
    pause 20
  next
return

back:
  for x=1 to 100
    pulsout 14,850
    pulsout 15,650
    pause 20
  next
return

left:
  for x = 1 to 100
    pulsout 14,650
    pulsout 15,650
    pause 20
  next
return

right:
  for x = 1 to 100
    pulsout 14,850
    pulsout 15,850
    pause 20
  next
return
```

Once you've downloaded the program, the robot should have moved forward, back, left, forward, and right. It will finish in a different location from where it started. If it quivered and didn't move, then you'll need to verify that it's working from a full 6.0 volts and that the servos were properly modified. If there's no response then check the schematic to see that the BASIC Stamp I/O pins are connected to the right servos.

In looking over the program, understand that the pulsout 750 centers the servo so it will not move. Anything larger than this will cause the servo to rotate clockwise, and smaller values will rotate counter-clockwise. Because one servo is reversed when they are used as a drive train, one is pulsed the opposite direction to make the robot move forward or backwards. The value of the 'for. . next' loop is proportional to the distance the robot travels in the specified direction. Modify the values in the program as you wish.

Now program your robot to move in several different patterns. Try the following:

- (a) Move in a square pattern with two-foot lengths by making three 90° left turns,
- (b) Move in a triangle by making two right turns,
- (c) Identify pulsout values that make the robot move forward very slowly, then backwards very slowly in a straight line.

## Conclusion

We built a Boe-Bot, and yours might look a bit different. You should have successfully loaded source code into your robot to make it execute some turns, forward, and backward movement. If you need some assistance with any aspect of your robot or the Boe-Bot, feel free to contact Chuck Schoeffler (chucks@uidaho.edu) or the Parallax support team (stampsinclass@parallaxinc.com). Next, we'll proceed to program your robot in detail by using the EEPROM to retrieve and store data, along with GOTOs and GOSUBs to structure your program.

RS&T

## Resources

### Parallax, Inc.

Boe-Bots, free educational curriculum,  
BASIC Stamps, and software  
3805 Atherton Road, Suite 102  
Rocklin, CA 95765  
(888) 512-1024 toll-free  
www.parallaxinc.com  
www.stampsinclass.com

### HVW Tech

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# RI/SME's Student Robotic Challenge Arrives in Pittsburgh, Pa. March 19-20, 2000

Students of all ages are prepping their robotic devices for the ultimate manufacturing experience – the RI/SME Student Robotic Challenge 2000.

Sponsored by Robotics International of the Society of Manufacturing Engineers (RI/SME), this event will be hosted by the Robert Morris College in Moon Township (Pittsburgh), Pa., March 19-20, 2000. "With its strong tradition of manufacturing, Pittsburgh is an excellent site for next year's competition," says SME President Cecil Schneider. "By participating in this challenging event, students develop a more thorough understanding of design and manufacturing and the rewarding and exciting careers available to them."

Middle school through university level students will demonstrate their understanding of manufacturing through a variety of manufacturing robotic and automation contests.

There will be hands-on robotic displays, corporate and school exhibits for the public to enjoy.

The new Millennium brings with it an expanded competition. In 2000, students nationwide will be enthusiastically preparing for the newly-expanded two-day Student Robotic Challenge. Elimination rounds for select contests are scheduled Sunday, March 19, and finals take place Monday, March 20. (In 1999, over 600 students and instructors from 11 states attended.)

Students can choose from 14 competitions. The specific categories and their goals are:

**Automation Work Cell:** design, build and operate an automation work cell that performs one or more manufacturing processes to produce a product.

**Block Scramble:** determine the sequence to transfer randomly stacked blocks from one spindle to another.

**Flexible Manufacturing:** re-program a cell to perform a change order given for a product.

**Journey Robot (Remote-Controlled & Self-Controlled):** design, manufacture and operate a robot that will proceed over a series of obstacles.

**King/Queen of the Hill:** design, build and demonstrate a remote-controlled device that can retrieve and deposit an object in various locations.

**Lunar Object Search (SAMMIE):** design, build and operate a remote-controlled vehicle that will traverse a simulated lunar environment in search of a designated object.

**Pick and Place Programming (Computer-Assisted & Teach Pendant):** program a table-top robot to pick up designated objects and place them in a specific location and order.

**Product Design/Manufacturing:** design, build and demonstrate a soccer ball kicker. Report the manufacturing system's design.

**Robot Construction (Open):** design, build and demonstrate a robot that performs any type of task(s).

**Robot Maze:** design and build or assemble a "mouse" that successfully navigates a maze.

**Robot Problem Solving (Rapid Application Development):** design and build a solution to a problem that occurs in a manufacturing plant.

**Robot Simulation:** program a robot in a virtual reality environment to perform various work cell activities.

**Sumo Robot (lightweight and heavyweight):** build a Sumo robot that forces another Sumo robot outside of an eight-foot circle.

**Up and Down the Staircase:** design, build and demonstrate a device that climbs up and down three-stair risers.

For additional information about the RI/SME Student Robotic Challenge 2000, contact Katie Ferrell, SME Education Department, One SME Drive, P.O. Box 930, Dearborn, MI 48121. Phone: 313/271-1500, ext.1704; Fax: 313/336-7065; e-mail: ferrkat@sme.org. Visit the SME Homepage [www.sme.org](http://www.sme.org) and check out photos of the 1999 competition. For more details about manufacturing engineering and SME, log on to [www.manufacturingiscool.com](http://www.manufacturingiscool.com).



# Winning the Journey Contest

## With a Scratch-Built 10-inch Automatic Guided Vehicle

by Gene Burbeck



*Three years in a row, this Pioneer High School student (Ann Arbor, Michigan) won the Journey Robot Contest conducted by Robotics International of the Society of Manufacturing Engineers (RI/SME). The obstacle course was curvy and bumpy, and defeated almost every autonomous design. But Gene's inexpensive scratch-built rolling robot, essentially a wooden board with a Parallax Basic Stamp on it, completed the course and won.*

*Here Gene describes the evolution of his winning design and his last minute ingenuity under pressure that earned him first place in 1998.*

I built two prototypes for my robot. The first one used a Rebound (RC car) for the chassis. It was controlled by a BASIC Stamp revision D, a serial servo controller, and a pair of electronic speed controllers. For sensors it used two active infra-reds looking forward and revolution counters on the wheels. The downfall of this prototype was that it was too fast and hard to control. If the course had had walls instead of black lines for following, I think this prototype could have gotten through it in less than 30 seconds. The robot would have used the walls for fast and accurate positioning to greatly reduce dead reckoning errors (more reliable send-off positions for dead reckoning segments). The robot would have been able to drive very quickly to its next reference point, push up against the wall to make itself perfectly perpendicular to the wall, and then execute the next dead reckoning leg with near perfect accuracy.

To cope with the problems of control, I used stepper motors on the second prototype. They were controlled by a BASIC Stamp II and a pair of stepper controllers I built right on the carrier board. The chassis was constructed of foam core. It used one active infrared sensor looking down. This robot could do everything except climb the hill. The standard Rebound chassis had a gear ratio that was too high. The robot needed to drive slowly enough to consistently sense lines and accurately execute dead reckoning legs. To obtain this low speed, the throttle setting needed to be very low. Therefore the vehicle's speed was easily affected by changes in resistance (hills, bumps, etc.) simply because there was so little power running the motors when the robot was moving at the speed necessary for optimal accuracy. Increasing the power to the motors to successfully climb the hill would have required adding another processor or similar device necessary to enable servo control of the motor speeds.

The final version used the same electronics as the second prototype, except for the sensor. The sensor is a passive infrared sensor. There are two of these looking at the ground, but only the left one is used. I geared down the stepper motors with a belt in a figure eight. This does not allow for backward travel, but provides more power for going up the hill. The chassis itself is made of two layers of Plexiglas with wood sandwiched in between. The batteries and front caster are inside this structure. The BASIC Stamp II is on top.

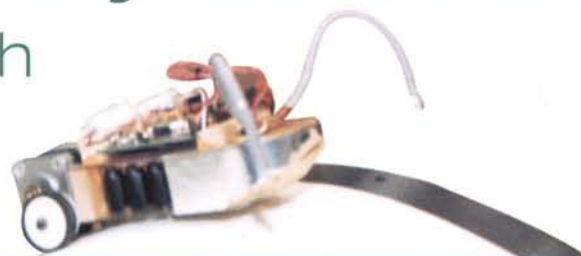
On the evening before the competition, when I tried the robot on the real track, I found—as did the other contestants—that the hill

was constructed slightly differently from the drawing in the competition guidelines manual. The initiation of the incline for the hill was too abrupt, causing the nose of my robot to hit the ground and get stuck as it started up the hill. My dad helped me make some quick adjustments to the chassis by cutting off part of the nose with a circular saw we borrowed from one of the contest setup crew. The tires also slipped when going up hill so I sprayed them with adhesive. In the end, my robot was the only one to make it over the hill.

At the bottom of the hill, the robot needed to make a sharp right turn. I deliberately used very slender, hard rubber tires for greater accuracy in the dead reckoning legs of the course. The hill was so steep that the robot's slender drive/brake wheels lost traction and skidded as the robot went down the hill. Since the turn was very close to the bottom of the hill, the robot did not have enough traction to slow down and turn before reaching the bottom.

Through trial and error, I had optimized tire width and hardness to match stepper motor power. Each tire would lose traction just before the maximum torque threshold of its stepper motor was reached. If I increased the traction of the tires, I ran the risk of passing the torque threshold of a stepper motor, thereby causing the motor to skip steps rather than just slipping its tire slightly. Skipping steps on one of the stepper motors while climbing the hill would have caused such major changes in direction of the robot that it would have "lost the line" and not been able to find it again. This prevented me from increasing tire traction enough to keep the robot from slipping when it went down the other side of the hill. Perhaps I could have used slightly wider tires and gained enough traction to negotiate both sides of the hill. But by the time I got to the contest site and discovered how steep the hill was, it was too late for such a major adjustment. The ideal solution for the steeper hill would have been more powerful stepper motors combined with higher traction tires.

I could see only one alternative in the time remaining, so I reprogrammed my robot to go straight across that line and turn right when it reached the circle. I explained the problem and my "on the fly" solution to the judges as we watched my robot go through the course. The rules being the rules, my score was reduced. However, only touching/crossing the lines once for my entire run did not have a major impact on my score.



# SME 1998 Student Robotics Automation Contest

## Self-Guided Journey Robot Event

### Source Code for Basic Stamp II Microprocessor

This program controls a journey robot through a 30' x 12' course using subroutines for following black lines, turning and driving straight. The program drives the robot at different speeds throughout the course. The robot uses a combination of passive infrared sensing and deduced reckoning (dead reckoning). The program logic allows the robot to know exactly where it is on the course throughout its journey, including aligning itself on the straight lines in the course to accurately set up the dead reckoning sections.

\*\*\*\*\*VARIABLES & INITIALIZATION\*\*\*\*\*

dirs=%1100000000000011 Set I/O pins on STAMP

result	var	word	Value returned from sensor
speed	var	nib	Speed in ms/step
threshold	var	word	Value between light and dark
l_tries	var	byte	Consecutive attempts to turn left
r_tries	var	byte	Consecutive attempts to turn right
steps	var	word	# of steps to be driven/turned
counter	var	word	Multipurpose counter

speed=3  
threshold=5000

\*\*\*\*\*MAIN\*\*\*\*\*

The MAIN function was reprogrammed once I arrived at the competition. I had to do this because of idiosyncrasies in the course not identified in the competition guide book. I did however get a fair amount of practice programming at home with courses laid out on the basement floor using black duct tape. MAIN is divided into LEGS so that the robot can be started part way through the course. This makes testing faster and wastes fewer batteries.

MAIN:  
pause 100 Wait 1/10 sec after 'on' switch closed, allows time to remove hand prior to robot moving

leg1: From start of funnel to start of pit area  
 gosub follow Follow the left side of the funnel  
 steps=300:gosub drive 4 lines dead reckon to left side of pit  
  
 steps=160:gosub left\_turn  
 steps=200:gosub drive  
 steps=150:gosub right\_turn  
 gosub sense Drive until left side of pit area is found

leg2: From start of pit area to end of hill  
 gosub follow\_h

leg3: From end of hill to circle, first dead reckon, then look for circle  
 steps=400:gosub drive then look for circle  
 steps=120:gosub right\_turn  
 gosub sense  
 steps=100:gosub right\_turn

leg4: Follows circle to the opening, then  
 gosub follow dead reckons across circle and on to finish  
  
 speed=2  
 steps=300:gosub drive  
 steps=160:gosub left\_turn  
 steps=1900:gosub drive  
 steps=190:gosub right\_turn  
 steps=740:gosub drive  
 steps=170:gosub right\_turn  
 steps=2250:gosub drive  
 end

\*\*\*\*\*SUBROUTINES\*\*\*\*\*

FOLLOW: Follows black line until line ends or makes a sharp turn  
 r\_tries=0  
 l\_tries=0

loop:  
 if r\_tries=200 or l\_tries=25 then goback  
 high 11  
 pause 1  
 rctime 11,1,result  
 if result<threshold then left\_curve

right\_curve:  
 steps=1:gosub right\_c  
 l\_tries=0  
 r\_tries=r\_tries+1  
 goto loop

left\_curve:  
 steps=1:gosub left\_c  
 r\_tries=0  
 l\_tries=l\_tries+1  
 goto loop

goback:  
 return

FOLLOW\_H: Same as FOLLOW, but creates more power for getting up the hill  
  
 r\_tries=0  
 l\_tries=0

loop2:  
 if r\_tries=200 or l\_tries=50 then goback  
 high 11  
 pause 1  
 rctime 11,1,result  
 if result<threshold then left\_curve

right\_t:  
 steps=1:gosub right\_turn  
 l\_tries=0  
 r\_tries=r\_tries+1  
 goto loop

left\_t:  
 steps=1:gosub left\_turn  
 r\_tries=0  
 l\_tries=l\_tries+1  
 goto loop

SENSE: Drives 4 steps, then look for line  
 steps=4:gosub drive  
 high 11  
 pause 1  
 rctime 11,1,result  
 if result<threshold then sense  
 return  
 \*\*\*\*\*STEPPER MOTOR CONTROL\*\*\*\*\*

These subroutines are called by MAIN or by other SUBROUTINES.

LEFT TURN: Runs right motor for counter steps  
 debug cls,cr,cr," <—"  
 for counter=1 to steps  
 pause speed  
 out15=1  
 pause speed  
 out14=1  
 pause speed  
 out15=0  
 pause speed  
 out14=0  
 next  
 return

RIGHT TURN: Runs left motor for counter steps  
 debug cls,cr,cr," —>"  
 for counter=1 to steps  
 pause speed  
 out0=1  
 pause speed  
 out1=0

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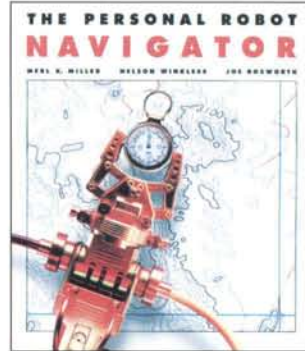
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```

pause speed
out0=0
pause speed
out1=1
next
return
DRIVE:
debug cls," ^",cr,"
for counter=1 to steps
  pause speed
  out0=1
  out15=1
  pause speed
  out1=0
  out14=1
  pause speed
  out0=0
  out15=0
  pause speed
  out1=1
  out14=0
  next
return

```

*Alternates stepper  
motors for steps steps*

*"",cr," |"*

```

LEFT_C:
for counter=1 to steps
  pause speed
  out15=1
  out0=1
  pause speed
  out14=1
  out1=0
  pause speed
  out15=0
  out0=0
  pause speed
  out14=0
  pause speed

```

*Runs motors in 3:4  
(left:right) ratio to  
follow black line*

```

out15=1
out1=1
pause speed
out14=1
out0=1
pause speed
out15=0
out1=0
pause speed
out14=0
out0=0
pause speed
out15=1
out0=0
pause speed
out14=1
out1=1
pause speed
out15=0
out0=1
pause speed
out14=0
out1=0
pause speed
out14=1
out0=0
pause speed
out15=0
out1=1
pause speed
out14=0
next
return

```

RIGHT\_C:

```

for counter=0 to steps
  pause speed
  out0=1
  out15=1
  pause speed

```

*Runs motors in 4:3  
(left:right) ratio  
to follow black line*

```

out1=0
out14=1
pause speed
out0=0
out15=0
pause speed
out1=1
pause speed
out0=1
out14=0
pause speed
out1=0
out15=1
pause speed
out0=0
out14=1
pause speed
out1=1
pause speed
out0=1
out15=0
out14=0
pause speed
out1=0
out14=0
pause speed
out0=0
out15=1
pause speed
out1=1
pause speed
out0=1
out14=1
pause speed
out1=0
out15=0
pause speed
out0=0
out14=0
pause speed
out1=1
next
return

```

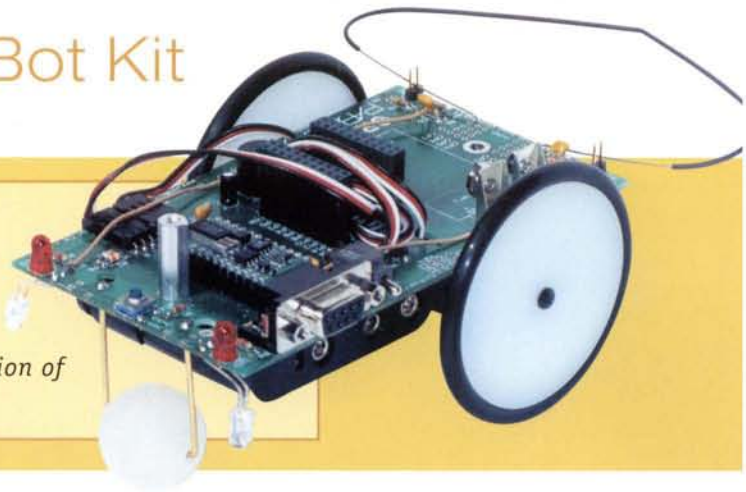
# Winning Against the Obstacles

## With a Modified GrowBot Kit

by Gene Burbeck

*After winning the national RI/SME Journey Robot Contest in 1997 and 1998 with his scratch-built robots, Gene tackled the next year's competition with a kit from Parallax, Inc.*

*Here Gene describes his construction and modification of the GrowBot, with which he captured gold in 1999.*



### Description

The GrowBot is a great little robot, simple to assemble, and easy to program. It is ideal for a beginning robot enthusiast as his or her first robot. It would also be ideal for a middle school, high school, or college beginning robotics class project. The GrowBot is designed for line following, obstacle avoiding, and general wandering behaviors. But as you'll see below, you'll want to make custom modifications to improve the GrowBot's dead reckoning ability.

The only abilities needed to build and use this kit are basic soldering, simple BASIC programming, and a general knowledge of electronics.

The robot is not intimidating. It is 3-1/2 inches wide, 2-1/2 inches tall, and 5-1/2 inches long, with a thin wire bump-sensor mounted on the front of the chassis.

The circuit board itself makes up the robot chassis. It has a standard DB-9 connector for programming the Basic Stamp 2-IC conveniently placed right on the edge where it is easily accessible.

Two servos-motors, which you'll modify for continuous rotation, are attached underneath. Each wheel is 2-3/4 inches in diameter and attached directly to the corresponding servo shaft. A one-inch plastic caster serves as the rear wheel.

Four AA batteries underneath the robot power the servos. A 9V battery on top of the robot powers the electronics. Using two separate power sources for brawn and brain keeps the brain isolated from electrical spikes and dips generated by the motors.

There are three sensors:

Thin wire bumper detects location of impact: left, middle, and right;

Two phototransistors detect light;

A push-button that is already wired to an I/O pin on the Basic Stamp.

There are three output devices. All are software controllable and are hooked to various I/O pins on the Basic Stamp 2:

A small, yet loud piezo buzzer – could be used for debugging or perhaps for communicating with other robots;

Two LEDs – could be used as active illuminators for infrared sensing or for debugging or communicating with other robots;

Two servos, each turning a wheel.

### Building

It took me about two hours to build the GrowBot. The kit comes with excellent instructions: step-by-step, and very clear. The instructions first call for soldering all the components onto the printed circuit board (PCB). I found it easy to put the PCB in a vise, topside up, and solder most everything from the top. I also left all the leads uncut until I was done with this step, and then turned the PCB over to cut all the leads at that point.

The instructions then call for mounting the servos, wheels, battery holder, and bumper.

Tools used:

Soldering iron

Small diagonal cutters

Extra-small and small Philip's head screwdrivers

Small file for smoothing ends of leads sticking through the PCB – I did this in order to mount the AA battery holder flat against the PCB.

### Programming

The GrowBot comes with a diagnostic program already in the BS2 EEPROM to test all systems on the robot except the photoresistor. Programming is done in the BASIC Stamp 2 version of Parallax BASIC, which I like a lot better than the version for the Basic Stamp because you can nest subroutines four deep. Programs are stored in EEPROM, so memory is non-volatile (turning off the robot does not cause the program to be lost). The kit comes with the Windows 95 version of the debugging/downloading program, which is much nicer than the DOS one. Even though the Basic Stamp 2 runs (line-by-line) interpreted code (instead of compiled code), it is still quite fast. It cannot multitask, but overall, it has plenty of computing power for the GrowBot. The GrowBot comes with several sample programs to do simple things like wander and use the speaker.

### Performance

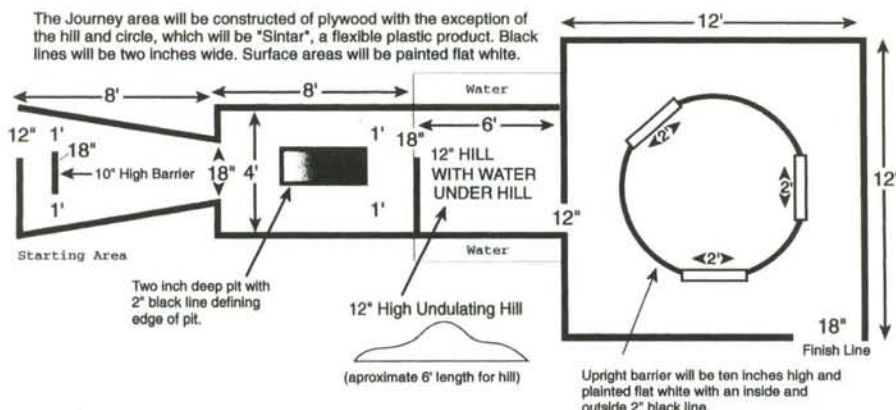
The GrowBot is a great robot for wandering programs, with excellent sensors and programmability for responding to sensory data. The kit uses quality materials, comes complete with all necessary

parts, and comes with excellent instructions. It is well constructed: has adequate clearance underneath, and is very stable on rough terrain. It has enough power to climb steep hills, though a little more speed might be nice.

I found only a couple of negatives to this robot: No spare parts are included in case you destroy a part during assembly (I luckily never had this problem). Also the lack of repeatability in the servos makes the GrowBot not very good for dead reckoning (servo speed depends upon the charge of the batteries which is not consistent between full charges).

It back on track several times because of the dead reckoning problem, especially on the hill section. (The hill was quite steep and circuitous. It was nice that the GrowBot had plenty of power to get up the hill. It was very frustrating, though, because it was not possible to program the dead reckoning sections precisely enough to navigate the ups and downs and twists and turns well. Even with a freshly charged battery, the battery charge was not totally consistent from one run to the next.)

### Journey Robot Schematic



## Customization

### Mechanical:

I turned the robot around so that the back became the front. I did this in order to get the maximum distance between the sensors and the driving wheels. This is better for following lines and results in less oscillation, and detects ends of lines faster and more reliably.

I also put two phototransistors on the new front of the robot. I used phototransistors because they are more directional and faster updating than the photoresistors included with the kit.

### Software:

After experimenting with the programs included with the kit, I began writing my own program with a completely blank slate. The event in which I entered the GrowBot was mostly a line-following course, with two interruptions of 12" or so between the end of one line and the beginning of the next. The robot needed to navigate from one end of the course to the other, including crossing through the center of the circle near the end.

I wrote a program (see next page) that was a combination of dead reckoning and line sensing to get through the course. The most essential dead reckoning section solved the problem of "never reaching the island by following the shoreline." (This dilemma is described and solved in RS&T issues 2 & 3.) Other dead reckoning sections simply made the robot's path more efficient.

I wrote separate subroutines for following a line, for detecting the end of it, and for basic dead reckoning maneuvers. The subroutines were then combined to create the *main* function, which is course-specific. I practiced creating this main function by laying out a course with black duct tape on my basement floor. Once I was able to do that, I knew I could easily adapt that to create the main function for the actual contest course once I arrived on the contest site.

The robot performed reasonably well at the competition - at least it was good enough to win the gold award! I needed to gently push

Here are some possible modifications to solve the problem of the inconsistency of the servos:

### Odometers:

Place an odometer on one or both wheels to count fractions of revolutions. This could be an incremental encoder on a wheel. Or, if there is space for it inside the servo, one could use a tachometer on the motor itself or on one of the gears if the frequency is too high.

### Stepper motors:

Completely replace the servos with stepper motors. The stepper motors would need additional batteries to power them. One 9-volt battery powering each stepper would be good. The disadvantage to using steppers would be that they are electrically inefficient and less powerful. (In the case of this competition, the power of the kit's servomotors was a definite advantage in negotiating the hill.)

Regulated voltage: Run the power to the servos through a 5-volt regulator. Use batteries powering the voltage regulator that will still have at least 5.5 or 6 volts in them by the end of the course. This means the servos will always be getting 5 volts, no matter what the battery charge. Note: The regulators may need heat sinks to keep them cool.



Gene Burbeck started building motorized Lego creatures when he was six years old. Soon after, he made radio-controlled Lego vehicles. Starting in sixth grade with a basic electronics book and a supportive mom and dad, Gene began consistently winning at school robot events. After winning the national RI/SME 97 and 98 events, he learned C programming at the University of Michigan School of Engineering summer camp, Camp CAEN. In 99, he returned to RI/SME to win again. He'll graduate high school in 2001.

## GrowBot Journey Robot Contest Program

```
vars:           'initialize variables
steps          var           word
counter       var           word
l_light       var           word
r_light       var           word
threshold     var           word
l_count       var           byte
r_count       var           byte
countdown     var           byte

calibrate:    'manually calibrate to light conditions
gosub update
threshold = 3566

main:         'course-specific main function

leg1:        'along the funnel to edge of pit
gosub follow
steps = 70 : gosub right_t
steps = 800 : gosub forward
steps = 65 : gosub left_t

leg2:        'along pit and over hill
gosub follow
steps = 20 : gosub right_t
steps = 1000 : gosub forward
steps = 120 : gosub left_c
steps = 800 : gosub forward
steps = 130 : gosub right_c
steps = 1000 : gosub forward
gosub sense
steps = 70 : gosub right_t

leg3:        'follow circle and go through it
gosub follow
steps = 150 : gosub forward
steps = 123 : gosub left_t
steps = 2150 : gosub forward
steps = 90 : gosub right_t
steps = 20 : gosub right_c
gosub sense
steps = 60 : gosub right_t

leg4:        'follow line to edge of course
gosub follow

end

sense:       'loop while driving forward until a line is found
gosub update
steps = 2 : gosub forward
if l_light < threshold then sense
return

forward:     'drive forward for a given number of steps
for counter = 0 to steps
pulsout 12, 550
pulsout 13, 950
next
return

left_t:      'turn left for a given number of steps
for counter = 0 to steps
pulsout 12, 550
pulsout 13, 550
next
return

right_t:     'turn right for a given number of steps
for counter = 0 to steps
pulsout 12, 950
pulsout 13, 950
next
return

left_c:      'curve to the left for a given number of steps
for counter = 0 to steps
pulsout 13, 550
pulsout 12, 550
pulsout 13, 950
pause 5
next
return

right_c:     'curve to the right for a given number of steps
for counter = 0 to steps
pulsout 12, 950
pulsout 13, 950
pulsout 12, 550
pause 5
next
return

update:      'update variables holding light sensor values
high 0 : pause 1 : rctime 0, 1, l_light : low
high 7 : pause 1 : rctime 7, 1, r_light : low
return

follow:      'follow a line on the left side
countdown = 0
loop:
l_count = 0
r_count = 0
countdown = countdown + 1

follow_l:
gosub update
if l_light > threshold then track_r
if l_light < threshold then track_l

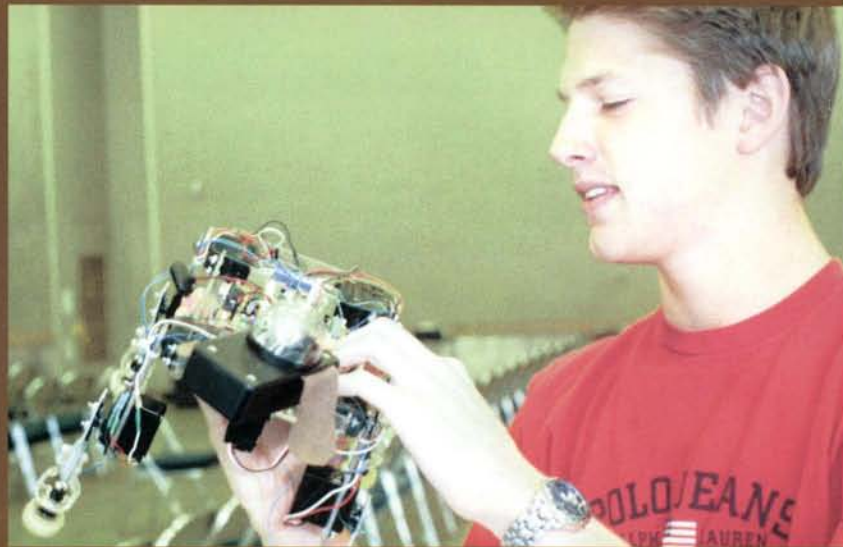
track_l:     'correct to the left and check for end of line
r_count = 0
l_count = l_count + 1
steps = 1 : gosub left_c
if countdown < 120 then loop
if l_count < 30 then follow_l
return

track_r:     'correct to the right and check for end of line
l_count = 0
r_count = r_count + 1
steps = 1 : gosub right_c
if countdown < 120 then loop
if r_light < threshold then follow_l

return
```

# RS&T

## ON-SITE AT THE SRS ROBOTHON 99



Grand Prize Winner Ryan Wistort with Rodney

*"At a point in our world where science fiction meets reality there exists a battle known as Robothon 99." — SRS*

Autonomous robots compete for glory, and the host is the Seattle Robotics Society ([seattlerobotics.org](http://seattlerobotics.org)). Here are some highlights of what RS&T saw in October at the Flag Pavilion at Seattle Center.

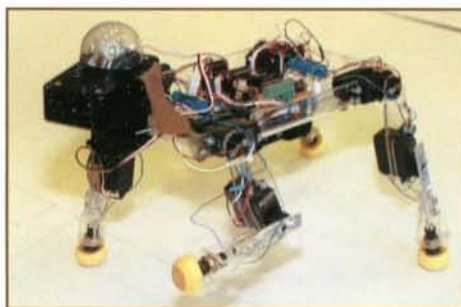
There are eight major events, well organized: Robot Sumo, Line Following, Fire Fighting, Lego Wars, The Grand Maze, Robo Art, a Floor Exercise and lectures by people who come from all around the country. Everything is autonomous, all machines have brains-on-board. RC not allowed.

I see a whole lot of people in the audience who wouldn't qualify as nerds. And I often hear some pretty excited roars and cheers, further proof that a robot contest is an emotion-packed spectator sport like horse racing or boxing.

The hall is loud, people are always in motion, moving from one event to the other. Randy Sargent plays *Tequilla* on a loud boom-box for three of Newton Labs' Mach 5 robots (mounted with Newton's Cognachrome Vision System.) At the first note of the upbeat rhythm, Newton's middle robot makes a brisk turn and all three bots zip into place, spinning, jerking in sync with the music.

There's not enough room in this issue to describe all the action at this first-rate event. So I found one robot that really captured everyone's attention.

A scratch-built dog-robot named Rodney, built by Ryan Wistort, a sophomore computer student at the high school in Gig Harbor. His machine is an four-legged walker made of quarter-inch Plexiglas. He shaped the plastic using a propane torch to mold curves around common household objects to make very smooth edges. (He laid the Plexiglas on a table and bent it down until



Ryan named his robodog Rodney, honoring the subject of this issue's interview. (See page 45.)

he got a nice curve and 90 degree angle, then turned off the heat.) The walker uses three PIC 16F84s programmed in PBasic. The whole thing, brain and motors, is powered by six double-AAs.

Rodney has a decidedly mechanical gate with more sophistication than elegance. The predictable order in which it moves and its jerky motions give it a supremely robotic feel. The head moves slowly from left and right. Rodney developed after five months of experimenting with designs, throwing them completely away and salvaging that which might be used in the next design. A true labor of trial and error and persistence.

Ryan earned Grand Prize for being the builder of the coolest robot, and capturing the essence of what the SRS is trying to do: trying new things and advancing the hobby.

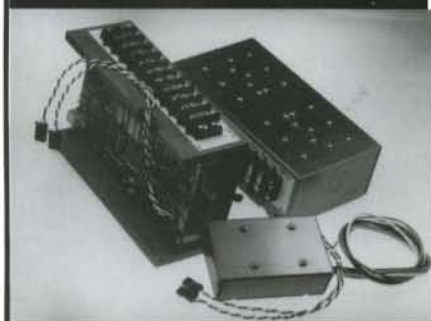
Congratulations to the winners of their contests: Gary Teachout, Daryl Sandburg, Mark Castelluccio., Lance Keizer, Tom Jenner, and Ani (3) and Bill Harrison.

In short, I'm impressed by the group of veteran roboticists from the long-standing Seattle Robotics Society who put on this show, especially Doug Kelley, Ted Greibling, Ron

Provine, Pete Miles, Tom Dickens, Bill Harrison and Gretchen Greene. And I'd like to extend my personal thanks to Roger Johnson for helping RS&T set-up our presence at the show. — Mike

*Post Script: The Northwest Robot Sumo Tournament will be May 20 in the Edmunds Community College gym near Seattle. See [www.SineRobotics.com](http://www.SineRobotics.com).*

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- 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.

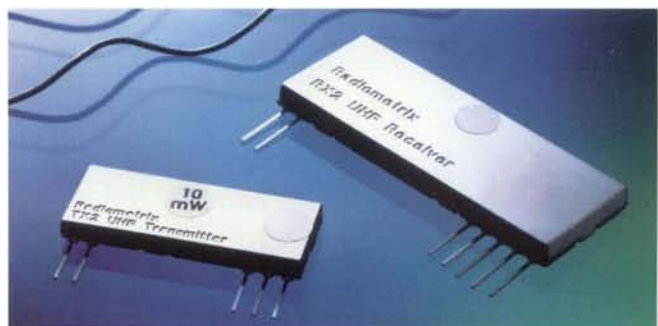
- ETS 300-220 tested for European use
- SAW-controlled FM transmission at -6dBm ERP
- Double conversion superhet receiver
- 107dBm receive sensitivity
- Single 4.5 to 5.5V supply < 15mA (tx or rx)
- Reliable 30m in-building range
- Half duplex data at up to 40kbit/s
- Direct interface to 5V CMOS logic
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- EMC conformant to ETS 300-683
- Type Approved to ETS 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

robotics • environmental monitoring • remote process monitoring • wireless PC printer links • energy management  
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# Pulse-Width Modulation Theory and Circuits

A hands-on experiment to control power ratio

by Tak Auyeung

## INTRODUCTION

Pulse-width modulation (PWM) is a common technique to control the power level of devices. PWM can be used to control the brightness of a light-emitting diode (LED), speed of a motor, heat of a electrical heating coil and many other applications. Because PWM requires minimal analog electronic hardware and saves energy, it is applicable to many devices used on robots, especially motors. In this article, we will first discuss the reasons and theories of PWM, then proceed to build a simple, yet flexible, PWM circuit for experimentation.

## Reasons for Pulse-Width Modulation

The most intuitive method to control the brightness of an LED is to control the continuous current passing through it. A variable resistor connected in series with the LED (see Figure 1) can control this current. An LED has a constant voltage drop when forward biased, and the voltage drop is usually about 1.7 V. Using Ohm's Law, the current passing through the LED is  $I = (V_{in} - 1.7V) / R$ , where  $V_{in}$  is the applied voltage and  $R$  is the resistance of the variable resistor. As  $R$  is increased, the current is reduced, and the LED dims.

Since most LEDs have a maximum continuous current rating of less than 50 mA, power dissipation at the variable resistor is not a problem. However, for motors and other high-current devices, the variable resistor needs to dissipate much more energy. The power dissipation ( $P$ ) of an electrical device is the product of the voltage drop across the device ( $V$ ) and the current passing through the device ( $I$ ). In short, Power ( $P$ ) = Voltage ( $V$ )  $\times$  Current ( $I$ ), or  $P = V \times I$ . For a modest 5 Vdc motor with a coil resistance of 10  $\Omega$ , the stall current is  $5 \text{ V} / 10 \Omega = 0.5 \text{ A}$ . At half strength, the stall current of the motor is 50% of 0.5 A or 0.25 A. The variable resistor must have a value of 10  $\Omega$  as well. This means the voltage drop across the variable resistor

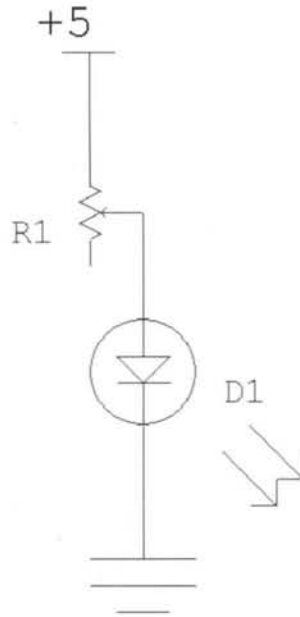


Figure 1: Variable Resistor Controlled LED

is 2.5 V. The current passing through the variable resistor equal the current passing through the motor, 0.25 A. Consequently the variable resistor and the motor must each dissipate  $2.5 \text{ V} \times 0.25 \text{ A} = 0.625 \text{ W}$ . While 0.625 W is not a lot of power most small printed circuit (PC) mounted variable resistors are rated for less than 0.625 W.

Many readers will immediately suggest the use of a power transistor to amplify the variable resistor controlled current (see Figure 2). This approach eliminates the power dissipation issue at the variable resistor. However, there is still a 2.5 V voltage drop across the collector and the emitter of the transistor, and thus there is still 0.625 W to dissipate at the transistor.

While the 0.625 W dissipated at the motor is mostly in the form of heat, the motor is developing torque (i.e. doing work) due to the current passing through the coil. However, the 0.625 W dissipated by the transistor or variable resistor is lost entirely as heat with no work performed. How can we stop this waste of 0.625 W of power?

Before discussing the obvious answer, let's consider the other drawback of using a variable resistor (regardless of using a transistor in conjunction). While a human can turn the knob and easily control a variable resistor, a computer cannot control a variable resistor as easily. There are electronic variable resistors that a computer can control, but they are extra components and impose costs, both in dollars and complexity (reliability).

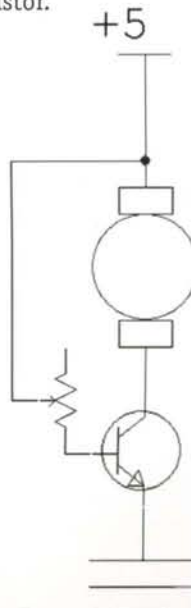


Figure 2: Transistor controlled 5V motor

Pulse-width Modulation not only addresses the wasted power issue, but it also eliminates the need of a variable resistor. In other words, PWM saves power while enabling convenient computer control. Some may argue that PWM is only convenient for computer-based control. As we will demonstrate later, it is quite inexpensive and easy to build a PWM circuit for non-computer-based and hands-on experimentation.

## Pulse-Width Modulation Concepts

The most fundamental concept of PWM is "duty cycle." Consider a gas furnace without gas pressure control. If only 50% of the full output is needed, the furnace can be switched on and off periodically. For a large building, switching the furnace on and off every 15 minutes is hardly noticeable because of the large "momentum" (heat capacity). The furnace outputs an average of 50% of its full output by operating at a 50% duty cycle. In our previous example, the on time is 15 minutes, and the period is 30 minutes (sum of 15 minutes of on time and 15 minutes of off time). Consequently, the duty cycle is  $15/30 = 50\%$ .

This concept of "duty cycle" can be extended to control the brightness of an LED and the strength of a motor. For an LED with a maximum continuous current of 20 mA, we can generate the same effects as a 10 mA continuous current by pulsing the LED at a 50% duty cycle with a 20 mA current. Obviously, if the LED is switched every second, the effect is blinking, not dimming. However, if the circuit switches the LED 50 times per second, the human eye can no longer perceive the blinking. Instead, the human eye sees a dimly lit LED. The same principle applies to motors. When pulsed every second, the motor is jerky. However, as the pulse frequency increases to about 100 Hz (100 pulses per second), the motor behaves as if the continuous current is reduced.

Thus, the frequency and duty cycle characterize a PWM signal. The frequency indicates the number of potential interruptions of continuous power in a given time frame ('potential' in that a 100% duty cycle PWM waveform has no interruptions), and duty cycle indicates the proportion of time that the signal is in an on state.

## Simple Circuit to Generate a PWM Signal

As mentioned earlier, some readers may argue that a variable resistor is easier to experiment with than a circuit to generate PWM. In this section, we will present a simple circuit that the reader can assemble quickly and inexpensively. The supplies required for this project should cost less than \$10 US, and the circuit is useful in many applications.

The core of the PWM circuit is two 555 integrated circuits (ICs). For those who are not familiar with the 555 IC, it is an IC designed for timing operations. For discussion purposes, we treat the timers as separate entities. The 555 IC can be configured for monostable (one-shot) or astable (oscillator) applications. In this application, one 555 IC (call it timer A) is configured for astable operation and the other (call it timer M) is configured for monostable operation. Timer

A generates the beginning of pulses (controlling the frequency), while timer M controls the on time.

Timer A, which determines frequency, is set up as shown in Figure 3. Both the threshold and trigger are connected to the timing capacitor. The oscillator operates in the following cycle:

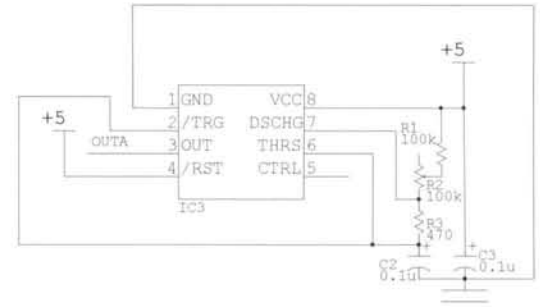


Figure 3: Timer A schematic

1. Discharge is disabled and capacitor C2 is charged through R1, R2 (note that R2 is a variable resistor, we are only interested in the effective resistance in the circuit, not the maximum resistance of R2) and R3. The output is high.
2. The capacitor is charged to  $2/3 V$  (V is the supply voltage to the IC). Consequently, the output is low and discharge enabled. Capacitor C2 is discharged through R3 to ground.
3. Capacitor C2 is discharged to  $1/3 V$  (where V is the supply voltage to the IC). The output is high and discharge is disabled. Go back to step 1.

The period of such a configuration is  $T = 0.693(R1 + R2 + 2R3)C2$  where T is the period (time) measured in seconds, R1, R2 and R3 are resistance measured in Ohms and C2 is capacitance measured in Farads. The amount of time per period when the output is low is  $R3 \times C2$ . For triggering another 555 timer, the low-output period can be short. In other words, R3 can be a small fraction of the sum of R1 and R2. The design can trade larger resistors R1, R2 and R3 for a smaller capacitor C2 or vice versa. For reduced power consumption, however, the total of R1 and R2 should be more than 10 kΩ. Because resistors are available in many values, it is easier to first select the value of the capacitor, then select resistors of appropriate value.

A 0.1 µF capacitor was used for timing and a 470 Ω resistor for R3. These values generate a low pulse of about  $(470 \times 0.1 \times 10^{-6})s = 47 \mu s$ , which is long enough to trigger timer M. We want timer A to have a frequency of 100 Hz (period of 10 ms). Recall that the period

$$T = 0.693 (R1 + R2 + 2R3) C2$$

With the known terms  $R3 = 470 \Omega$ ,  $C2 = 0.1 \mu F$  and

$$T = 10 \text{ ms}, R1 + R2 = (T / (0.693C2)) - 2R3 = 143 \text{ k}\Omega$$

For flexibility, R1 is a 100 kΩ resistor in series with R2, a 100 kΩ variable resistor for a range of total resistance between 100 kΩ and 200 kΩ. With this variable resistor, you can tune the frequency of the PWM by adjusting R2.

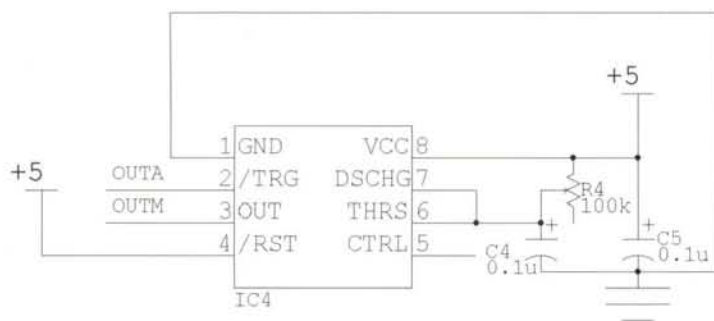


Figure 4: Timer M schematic

Timer M, which determines the on time, is set up as shown in Figure 4. As a monostable timer, the output of timer M is normally low, and the capacitor is normally discharged. However, when the trigger receives a low pulse (from the output of timer A), the output becomes high and the capacitor is no longer discharged. The capacitor is charged to  $2/3 V$  (where  $V$  is the supply voltage to the IC) and then triggers the timer output to become low and enable the discharge of the capacitor. The duration of high timer output is  $T = 1.1 \times R4 \times C4$ . Again, we are only interested in the effective value of  $R4$ , not the maximum resistance. For a 100 Hz PWM signal, the duration of high output can be up to 10 ms. Since the author had a 100 k $\Omega$  variable resistor available at the time of writing this article, the design calls for a 0.1  $\mu$ F capacitor. Optimally, based on the equation, the resistance  $R$  for a 10 ms pulse is  $10 \text{ ms}/(0.1 \mu\text{F} \times 1.1) = 90.9 \text{ k}\Omega$ . The 100 k $\Omega$  variable resistor covers the entire range and can therefore control the duration of pulses from 0 to 10 ms.

## Prototyping the Circuit

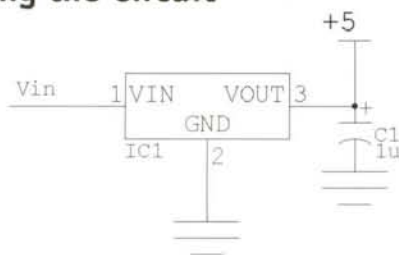


Figure 5: 7805 Regulator set up.

With the wide use of regulated 5 V supply for most complementary metal oxide semiconductor/transistor transistor logic (CMOS/TTL) ICs, a regulated 5 V supply will be used whenever possible. For cost effectiveness and convenience, a 9 V battery and a 7805 linear regulator to regulate the voltage to 5 V is recommended for use. A wall transformer that provides 9 Vdc to 12 Vdc, can be used as well. For this project, the power consumption should be less than 50 mA at 5 V, which makes the 9 V battery and 7805 regulator solution very reasonable.

The 7805 linear regulator is easy to set up (see Figure 5). The 1  $\mu$ F decoupling capacitor is not required, but it is good practice to use one to ensure stable regulated voltage.

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The following components are needed for the circuit:

- Two 555 IC timers (or one 556 dual timer IC)
- Two 0.1  $\mu$ F capacitors for IC decoupling
- Two 0.1  $\mu$ F capacitors for timing
- One 1  $\mu$ F (exact value is not important) for the overall regulated voltage
- One 100 k $\Omega$  resistor for timer A
- One 100 k $\Omega$  variable resistor for timer A
- One 100 k $\Omega$  variable resistor for timer M
- One 7805 linear regulator (if you do not have a regulated 5 V supply)
- One LED (optional to demonstrate PWM visually)
- One 220  $\Omega$  current limiting resistor (optional, for the LED)

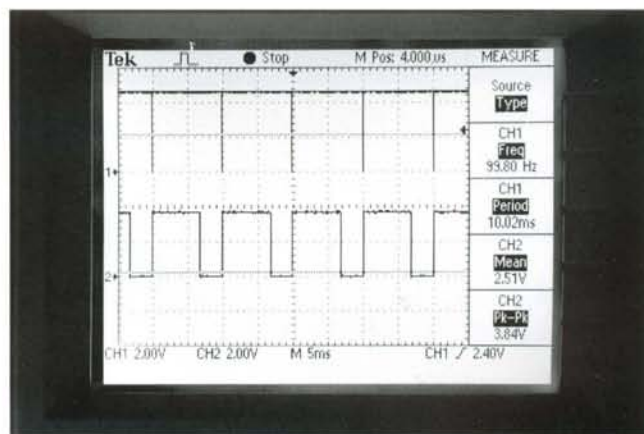


Photo 1: Oscilloscope screen shot of Timer A (frequency output at channel 1) and Timer B (duty cycle output at channel 2)

## Experimenting with the Circuit

There are many ways to construct a prototype circuit. If you are interested in learning how to wire wrap a circuit prototype, please refer to the wire wrap article (Issue 6, page 36). You can also construct the prototype on a breadboard or a soldered prototype board.

After the prototype is constructed, you can start to experiment with it. The first task is to measure the period of the output of timer A. Use either an oscilloscope or a multimeter to measure frequency. Some multimeters that can measure frequency cost as little as \$60 US. Since we used a variable resistor in the timer A circuit, you can adjust the variable resistor and watch the frequency change. See Photo 1 (channel 1) for a screen shot of the output from timer A on an oscilloscope. Connect the output of timer M to an oscilloscope to observe the actual wave (see Photo 1 channel 2), or connect the output to a voltmeter to observe the average voltage. Adjust the variable resistor in the circuit of timer M to adjust the duty cycle. Photo 2 shows an oscilloscope screen shot of timer A and timer M set to a different duty cycle.

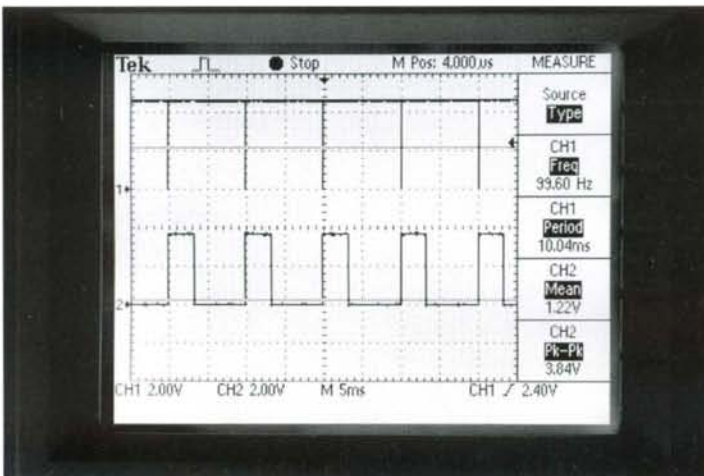


Photo 2: Oscilloscope screen shot of a duty cycle different from that of photo 1.

If you need to convince yourself that fast pulses are not visible to the human eye, you can visualize the effects using an LED. Do not connect an LED directly between the output of timer M and ground! Doing this will damage possibly both the timer IC and the LED. Most LEDs have a maximum continuous current of about 20 mA. To limit the current, you should connect an LED in series

with a 220  $\Omega$  resistor between the output of timer M and ground (see Figure 6). Because an LED has a voltage drop of about 1.7 V the resistor is responsible for about 3.3 V of voltage drop. According to Ohm's law, the current passing through the 220 resistor should be about  $3.3 \text{ V} / 220 \Omega = 15 \text{ mA}$ . You can use smaller current limiting resistor if the maximum continuous current of the LED is more than 15 mA. As the variable resistor the timer M circuit is adjusted and the duty cycle changes, the brightness of the LED changes accordingly.

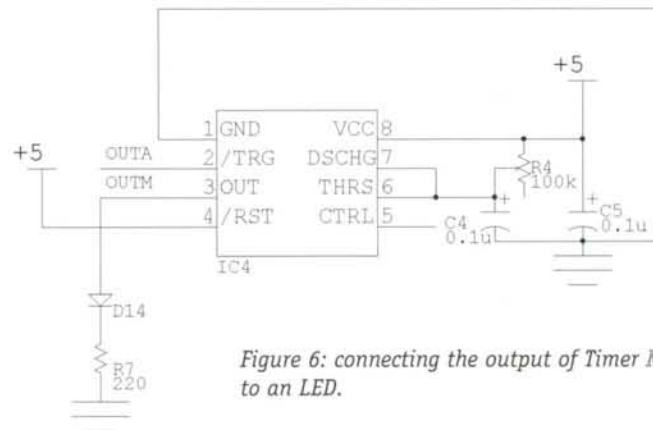


Figure 6: connecting the output of Timer M to an LED.

You should not connect the output of timer M to a motor. Although a CMOS timer output can drive up to 50 mA (sufficient for LEDs), it is no match for the demands of a motor! Furthermore, the timer IC has no protection against the electromagnetic feedback (EMF) of an inductive load (such as a direct current motor). Connecting the output of a timer to a motor probably will permanently damage the timer.

## The Next Project

This project seems to have very little to do with robots. However, knowledge of the operation of the 555 IC will be useful for many robot projects. Even more importantly, the technique of Pulse Width Modulation is very useful in controlling the strength of a motor. In the next article (see next page), we will look into the techniques of controlling a direct current motor, and the PWM circuit will be a component of that project.

## EXPERIENCED ROBOTICISTS WANTED:

Experts in all fields with hands-on robotics experience are cordially invited to submit story ideas or outlines to Editor@RobotMag.com, 3875 Taylor Road #200, Loomis, California 95650.

# DIRECT CURRENT MOTOR DRIVE

## Electronically Controlling a DC Motor

### Speed Control Experiment Using a 555 timer

In the previous article, we discussed how to generate a pulse-width-modulated (PWM) signal. However, the author explicitly cautioned *not* to connect the output of the 555 integrated circuit (IC) timer to a motor. This is due to the current requirement and the electro-magnetic feedback (EMF) of a motor. In this article, we will experiment with a circuit that enables speed control of a DC motor with 555 IC timers or any transistor transistor logic (TTL) device.

### The Switch-On Conditions

The stall current is the amount of current passing through the motor coils at a known voltage when the motor is not moving. When the motor is not moving, the inductance and the resistance of the coils determine the stall current. The inductance of a coil is denoted by  $L$  and measured in Henries (H). Inductance is the amount of electrical potential developed relative to the change of current. A high inductance inductor develops more electrical potential across the terminals than a low inductance inductor for the same amount of change of current.

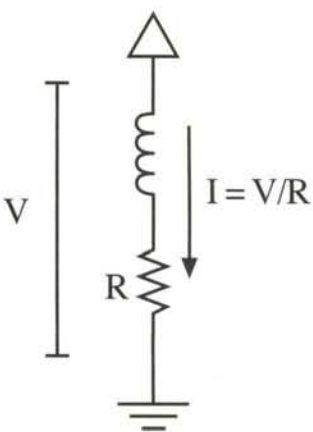


Figure 1. The stall condition of a DC motor.

Prior to a DC motor being switched on, there is no current flowing through the coils. When switched on, if the motor is not allowed to turn, the increase of current flowing through the coils is determined by both the inductance and resistance of the coil. A high inductance motor will take more time for the current to increase. However, at some point, the current stops increasing as the inductance has been overcome and resistance becomes the only factor stopping the increase of current. The stall current is measured at this point. Refer to Figure 1 for an illustration of the stall condition.

When you select a switch for the motor, it must be able to switch the stall current. For instance, if the stall current is 0.5 A, the switch component should be able to handle 0.5 A in the expected operation conditions.

### The Switch-off Conditions

Having discussed the switch-on conditions, what about the switch-off conditions? An inductive load (such as that of a motor) requires special consideration for the switching-off condition due to EMF. Electro-magnetic feedback can be explained by the definition of inductance. When the current to an inductive load is switched off, there is a sudden change of current flowing through the inductor. This sudden (that is, LARGE) change of current flow develops a proportionally large amount of electrical potential across the terminals of the inductor. See Figure 2 for an illustration. Such a high electrical potential causes the spark in automobile engine spark plug terminals. The electrical potential is developed when the current flowing through the ignition coil is suddenly stopped. Although the coil is energized by less than 14 V, the electrical potential of the EMF is high enough to cause an electrical arc across the fuel-air mixture in the cylinder!

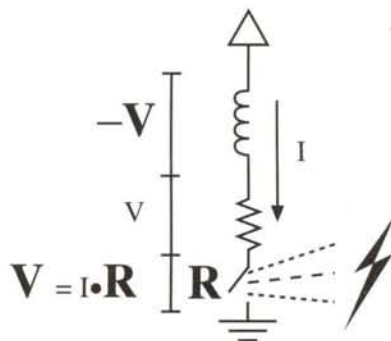


Figure 2. Sparking caused by suddenly switching off current through an inductor.

For a motor control circuit, EMF can be extremely harmful. If a relay is used to switch the current, the EMF causes arcing across the relay contact points, it can even weld the contact points together. If a transistor (bi-polar or field-effect type) is used to switch the current, the EMF damages the junctions in the transistor. Choosing a switch with a higher current capacity does *not* solve this problem.

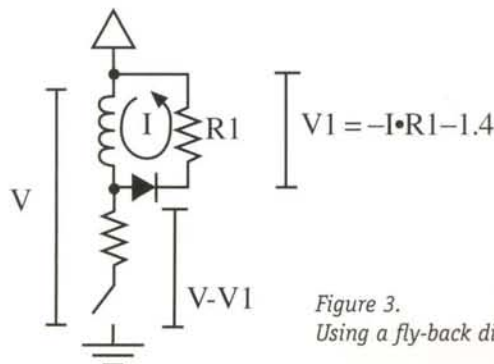


Figure 3. Using a fly-back diode to limit back-EMF.

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The solution to EMF is a fly-back diode in series with a resistor (figure 3). The fly-back diode and resistor provide an alternative route for the current flowing through the coil after the switch is turned off. The diode acts as a switch to enable this alternative route, while the resistor dissipates the energy. The instantaneous current in this circuit equals the current passing through the coil before the switch is turned off. Therefore, the voltage developed across the resistor is (according to Ohm's law)  $V = IR$ , where  $V$  is the voltage,  $I$  is the current and  $R$  is the resistance. The power dissipated is

$$P = VI = I^2R.$$

Note that the voltages developed across the resistor and the diode are added to the motor supply voltage at the switch. Consequently, you should make sure the switch (especially if it is a transistor) can

handle the sum of the voltage across the resistor and the motor supply voltage. The voltage across the diode is about 0.7 V, which is not a major contributor to the voltage applied to the switch.

## A Hands-on Experiment

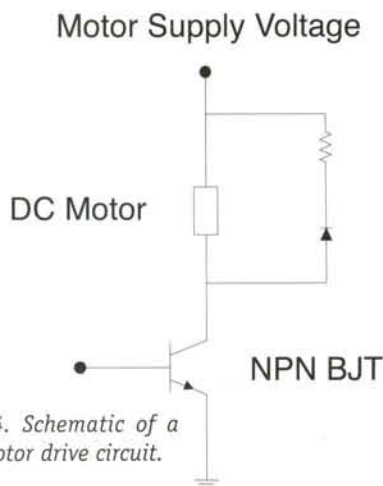


Figure 4. Schematic of a basic motor drive circuit.



Our hands-on experiment involves a motor rated at about 6 V with a stall current of about 0.5 A. You can find such a motor in most servos. The author modified a servo here at RS&T for this experiment. The modified Futaba servo's original circuit is completely disconnected. Instead, wires are connected directly to the terminals of the motor. The stopping tab at the final gear is also removed to allow full rotation. Thus, the servo becomes a gear motor.

The transistor selected is a 2N3053 NPN bipolar junction transistor (BJT). It amplifies the base current approximately 100 times, with a voltage drop of about 0.7 V across the base-emitter junction, and is rated for continuous 700 mA operation. While it was not rated at twice the stall current of the motor, it was the most suitable transistor available from the local RadioShack store. A base current of 5 mA controls the collector current to about 500 mA. According to Ohm's law, the base current limiting resistor should be

$$R = V/I = 5 \text{ V}/5 \text{ mA} = 100 \Omega.$$

Flyback diodes are available in great variety. The author chose a 1N914 diode, a fast switching diode, such as the 1N5819 could also be used. A 20  $\Omega$  resistor is selected as the power dissipation resistor. Assuming a maximum current of 0.5 A, Ohm's law indicates the voltage should be:  $V = IR = 0.5 \text{ A} \times 20 \Omega = 10 \text{ V}$

Since the motor supply voltage is less than 9 V, and the power dissipation resistor could develop up to 10 V, a total of 19 V, a 40V transistor can handle the surge.

This circuit can be connected to the PWM circuit in the previous article. Connect the output (pin 3) of timer M of the PWM circuit to the base resistor (100  $\Omega$ ) so that the resistor is between the output of timer M and the base of the transistor. As you adjust the variable resistor of timer M, the speed of the motor will change. In your experiment with this circuit, the transistor may become warm to touch, but should not get so hot that you cannot touch it continuously.

## The Next Project

So far, we have discussed PWM and motor movement, but not direction. The next issue will present an electronic device for switching the motor on and off and controlling its direction.



Editor/Engineer/Educator Tak Auyeung, PhD, was the software development group leader for embedded controllers at Zworld before jumping ship to RS&T. He teaches the micromouse lab at UC, Davis, and is best known to our readers for his search algorithm series in RS&T issues 2 - 5.

# A Conversation with Rod Brooks

*To many, he's a revolutionary thinker. He invented subsumption architecture and the behavior-based method of building robots to explore the cognitive sciences. His ideas were a radical change of approach to researching artificial intelligence. He believes that an intelligent robot must teach itself to survive and thrive in the real world; the dirty, dynamic world outside of theoretical simulations.*

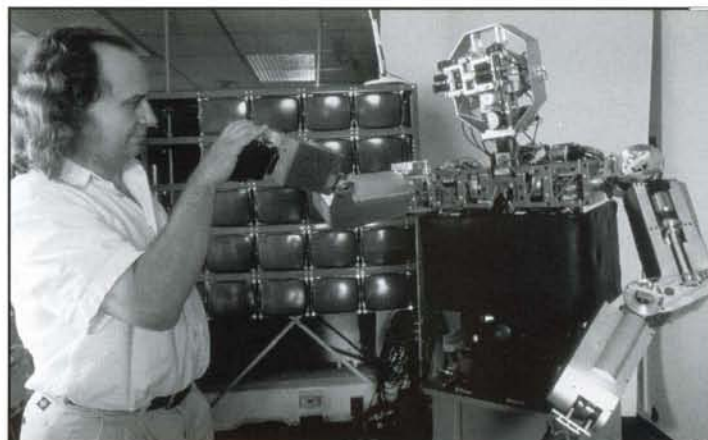
He is the Fujitsu Professor of Computer Science and Engineering; Rodney A. Brooks directs the Artificial Intelligence (AI) Lab at MIT. He is also Chairman and Chief Technology Officer at IS Robotics, a leading-edge product development company specializing in Artificial Intelligence, Man/Machine Interfaces, and Micro Robotics.

His ability to speak plainly to the public and his robots' ability to capture the public eye have earned him popularity with RS&T readers, and generated some measure of disapproval from more traditional researchers. In fact, while his papers are required reading in many classrooms, some textbooks will barely mention his methods.

His new book "Cambrian Intelligence: The Early History of the New AI" reports his research from 85-91. Before you read it, we thought you'd like to read a little about the man himself. So our nomadic publisher, Mike Greene, literally cornered Brooks in a convention hallway. Captured between a Pepsi cart and an out-of-service escalator, the Bad Boy of Robotics consented to converse.

At first glance, Rod Brooks could be mistaken for a jobless houseguest; his plain white shirt slightly expands over a soft belly, drooping over his belt buckle. You notice his long hair and slightly shy hairline, and he doesn't seem to care that his spectacles are wildly askew. This, combined with his brisk style of speaking gives the impression that he spends his time on just one all-consuming passion. His manner is unassuming, whether lecturing or chatting.

But the plain guise is misleading; at a question, his answer is swift, concise, correct, and obviously the refined product of more brain cells than most people will ever use. Read closely, he speaks quickly, and in Australian.



*Cog is Brooks' experimental testbed. See RS&T Jan 99 centerfold for more detail.*

*Are you building robots to understand humans better, or are you actually going for the Commander Data genre?*

With COG there is an element of both. The shorter term is to understand humans better. The longer term is to build Commander Data. So we have a mixture of those two goals. The different people working on the project may have very different goals.

The pure Artificial Intelligence part is to build Commander Data. That has sort of been the goal of AI, long term, although a lot of people won't admit to that. They will deny it, but that's what drives them underneath it all.

*How much has science fiction inspired you?*

Oh, quite a bit. When I was a teen-ager I read 2001: A Space Odyssey before I saw the movie. That was a great inspiration to me.

*How about details? Do you get some implementation ideas from fiction?*

No, the movies are normally too goofy. So, not details. I think "that can't possibly work that way. How could you really make it

work." The results are interesting but the way the movies explain it is too goofy. But then you start thinking how could you really do it and that is where good stuff comes from.

*What would you consider is the most important thing your team is doing at MIT?*

I think human-robot interaction, in the sort of ways that we don't even think of, the way we interact when we are talking to a person. There are all sorts of cues going back and forth which are cross-cultural, with eye motion, or grunting, uh-huh, nodding your head; all those sorts of things which are completely subconscious. But machines haven't done that before. We are trying to get that into the machine.

The new COG heads will be slightly better than the current KISMET head because we are putting in a bunch of stuff to do with neck geometry so that it can make much more natural head motions. Right now when it nods or shakes its head, it doesn't look natural because the kinematics are completely different from a human. So we are making it much more like a human. But then the new KISMET has a lot more degrees of freedom that we are not putting on COG. And also some non-human things too that we are experimenting with.

*Better than human?*

Well, actually more like cartoons. You know cartoon characters do things that humans cannot do, but they are very expressive and very natural. So we are experimenting with a neck thing that will stretch at the right time. You know, it's very cartoonish sort of stuff. But people really pick up on it and understand what is going on. I don't like to call it super-human in the sense of a superman, but it is super-human in the sense that it is stuff that humans cannot do. You can get across the information without having to be quite as good as a human, with fewer degrees of freedom.

*You're not confined to building a robot that mimics humans, but perhaps a robot that can work with humans even better than humans can work with humans?*

Yeah, although humans are so damn good that we can never meet their standards, right? So if we can do these other things maybe we can get around not being as good as humans on those aspects, by doing it a slightly different way. So we are experimenting with that.

*You're widely recognized as making lots of great contributions that are really revolutionary. Wouldn't you agree?*

Some people say that, and other people are not so complimentary.

*But I think they would all have to agree that you did change the way things are done in AI. Do you consider yourself working in AI or in robotics?*

I have always viewed AI as a sub-set of robotics.

*Not the other way around?*

Right. Which has really annoyed some AI people. So I like to think of myself as a robotics person and an AI person.

*What did it take to become a person like you? What kind of life-experience, inspiration and education?*

Well, I grew up in Australia, intellectually rather isolated. But I was always interested in building things. As early as I can remember I spent a large portion of my time buying either junk or scrap or simple stuff and trying to build the most complex machines that I could. From age eight or nine, that is what I spent all my time on. I was lucky in a way because I had to invent everything for myself and I didn't have access to lots of

really high technology, so I had to figure out how to build the stuff out of almost nothing. I would get access to books from the U.S. and England which would talk about all these wonderful inventions but there were things that I could never see or touch or learn about directly. So I had to sort of re-invent it all myself and that has given me certain skills and determination.

*Now why I was so interested in it I can't tell you. It was just something that was in me.*

*Were you top of the class in grade school, a bright, grade student?*

Yeah, pretty much.

*Genius I.Q.?*

Oh, I don't know about that.

*Modesty aside, really?*

I was recognized as being one with a special gift.

*And at eight or nine would you have called yourself a hobbyist, tinkerer? Into robotics or electronics?*

Yeah. It was electronics. I was always interested in computers and robots. To be honest, the building of mechanical robots that could actually do stuff was beyond my mechanical abilities. I was able to build computers more, because they didn't have all the high-precision moving parts. My things were always pretty rough and ready. So I was always trying to build computers to play games or do various things.

*Is there an Einstein in robotics?*

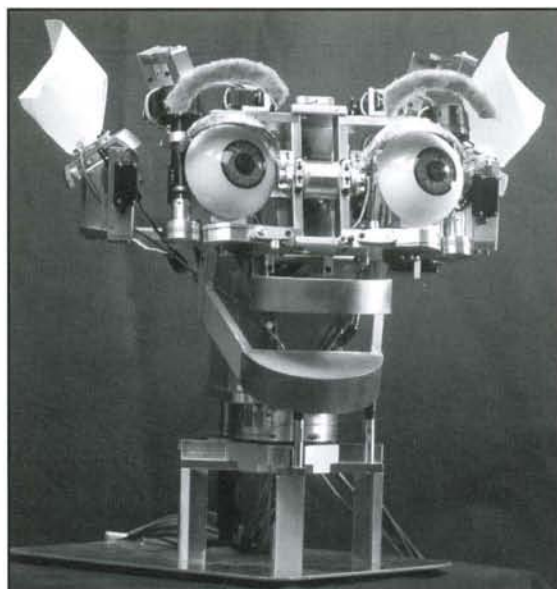


Photo Credit: Sam Ogden Photography/Boston

*Kismet's head displays emotions in response to yours, see more detail in October's Discover*



No.

*Do we need one? What are the consequences?*

Well, two or three wouldn't hurt. I don't think you can point out one. From an intellectual point of view, Alan Turing is the person you have to go back to. He has the inspiration. If you read his 1950's paper, "Computing Machinery," where he talked about robots and talked about artificial intelligence—that was very visionary. So he is Einsteinian in that sense, but not in the sense of there being one over-arching technical achievement like the theory of relativity was.

There hasn't been such an achievement and maybe there never will be. So it is harder to point to one person. You can point to various people who have done big things – Joe Engelberger (see RS&T Oct 99) did the first industrial robots, but I don't think you can compare him to Einstein; maybe you can compare him to Henry Ford.

I wouldn't say there is one big, big idea, in the way that Einstein had that big, big idea. The closest would be Turing.

---

*"Progress [in intelligent robotics] is happening astoundingly quickly and will continue to happen over the next few years. We are going to see a transformation of society in the same way the automobile transformed society at the turn of the last century."*

---

*Is there a group, or an inner circle — a Vienna Circle, if you will — of inner thinkers?*

No. Different people are working in different ways and they come together in different groupings at different times. There is a lot of cross-fertilization. I don't think it is as closed as that might suggest. In terms of maybe not a Vienna Circle but a Copenhagen Group. In terms of the quantum theorists, a bunch of people who are *in*.

But this field is much more open. I think a lot of people can make contributions to robotics. Actually one of the interesting things about your magazine that excited me was that this is a way to get more people involved who might be able to make contributions.

I don't think it is quite the same as the very theoretical physical sciences. It was very hard for an amateur to make contributions to quantum mechanics. But I think people working in isolation might well be able to do some interesting things that have a profound effect in robotics. I would like to think that there are a few Wright Brothers out there. Look at flight as the analogy rather than physics. The Wright Brothers were a couple of bicycle builders who had a passion. A lot of the other early people in flying machines were like them, they were spread out all over and they were able to make contributions.

*How does a young person get started in robotics?*

For the 10- and 11-year-olds, probably Lego MindStorms is a good starting point. And as they get older, I think that your magazine will be a great service to them, and it is the sort of magazine that I would have loved to have had as a kid.

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I read a magazine that was similar in the electronics domain, you know, with individual discreet transistors and vacuum tube circuits, when I was a kid. And that was what got me going. I see that role for your magazine.

*What education do you suggest for a young person wanting to make a contribution in robotics?*

That is tricky because robotics can be so broad. There is not just one education, there are lots of different people in robotics from different educational arenas and there will always need to be. Certainly you will need

some mathematics and some basic physics — some basic electronics, some basic computers and some basic mechanical engineering — and then specialize from that. There will be different specialists, of course, some that are more mechanical or more software, or electronics or whatever. But I think it is important to have a basis in all areas so you can appreciate the constraints coming from the other directions. Even if you are not the expert in it you should have an appreciation for it.

*How does a curious amateur grow up to be a leader in intelligent robotics? Is it an intellectual challenge only, or are there personality traits that are required?*

I think you have to have a passion for it, if you want to be a leader. It has to consume you, as it consumed the Wright Brothers. That is what they lived for.

*It consumes you?*

This is where I spend all my time.

*What do you do at home? Video games, TV?*

I have never gotten involved in video games. I watch *Star Trek*. All versions of *Star Trek*. And that is about it. I play with my kids and work.

I try to look at all the journals. I wouldn't say there is any one in particular. At various times I get very excited by various people. I can point to lots of interesting things I've read but...Well here is one that I read recently, the book is from 1927. It is "On Growth and Form" by D'Arcy Thompson. It is a *fantastic* book.

*Do you study ethical issues surrounding robotics? Do ethical issues affect your design?*

They don't affect the design. But I am certainly interested in them. We have a Lutheran minister here in the group, Anne Foerst. She has been running a seminar series here called "God and Computers." We are trying to think about where the issues are coming up; not being defensive against them, but trying to be *open* to them.

I think as we build more intelligent robots it is actually going to be a challenge to the foundation of organized religion because

people will no longer be as special as they were. That is going to be difficult for people to deal with.

*Do you identify with a particular religion yourself?*

I am a hard-core atheist.

---

*"A lot of people can make contributions to robotics... one of the things about your magazine that excited me was that this is a way to get more people involved who might be able to make contributions."*

---

*What role can amateur play? They're building autonomous fire fighters, soccer players, maze-following micro-mice. Are these things useful?*

Yeah, they are useful. a micromouse going to be useful? Sometimes the danger with the comp

petition is that you end up optimizing for the competition. So in micromouse-land you optimize for a certain set of characteristics. But the firefighting is more interesting because it is not quite as controlled, and so there is a tradeoff in the way you design for competition.

You have to design the competition so that people are exposed to lots of technology and they get familiar with how to put it together. And if they can understand that, as they go to bigger and different problems they will have to adapt their technology rather than just use exactly what they have learned in that one domain. And I think *that* is very useful.

*Do you have some advice for the students that are wanting to contribute? Or maybe just wanting to survive the schools?*

You are making me try to act like a sage here. I don't feel like a sage. I don't want to grow up! I am just bullish on robotics.

Things are really happening right now. Especially the last two or three years. It is a great time to be doing this because progress is happening astoundingly quickly and will continue to happen over the next few years. We are going to see a transformation of society in the same way the automobile transformed society at the turn of the last century.

*How can we see the credibility in that kind of statement? According to predictions made decades ago in popular science magazines, we're already supposed to be in a space-age 'Jetsons' era. Isn't it kind of dangerous to make a prediction that we are about to see a transformation of society?*

Yes, it is kind of dangerous, but it didn't stop me from doing it.

Look at the web. It didn't exist six years ago, and look at it now. At least in western society among technically literate people the web is used every day and is really part of our lives. In every advertisement, every magazine, there is a web address. That wasn't there six years ago. No one had heard of the web. So this is transforming the world around us as we speak.

*Robotics is going to transform society at the turn of the century.*

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# FEEDBACK LOOP

"...firefighting is interesting...there is a tradeoff in the way you design..."

Rod Brooks

## RS&T Guards the Coasts

Mike, October's was a great issue of *Robot Science & Technology*, though I must admit that I am biased toward the FIRST story and the two Lego MindStorms stories. I am already looking forward to your next issue, as I suspect that I know who your "interview with a revolutionary thinker" is. You may also be interested in covering Dean Kamen's latest invention, a "wheelchair" that is capable of balancing a single set of wheels, climbing stairs, and traversing rough terrain.

My sabbatical with FIRST ended in August, and I am now back to teaching full time at the Coast Guard Academy. In the fall, I run an experimentation class/lab, so I keep my hands in interesting areas. You'll be happy to know that I bought five sets of the Parallax Boards of Education thanks to one of the ads in your magazine. We'll be using the boards/software in a lab where students build and program A/D and D/A converters. Keep up the great work, and I look forward to seeing you again at one of the FIRST competitions. —Vince Wilczynski

*Commander Wilczynski teaches technical labs at the US Coast Guard Academy, and has been a tireless, enthusiastic and invaluable organizer of FIRST high-school robotics competitions. (See RS&T Oct 99.)*

## A Great Issue

Issue #6: Great Issue! I especially like the article on the sharp GP2D02 and 05 sensors. Keep up the good work! —Bob Harbeck *Note: Bob has given us several solid story leads during the past year. Thanks, Bob.*

I have enjoyed every issue of RS&T from the first to the latest. My son and I found many of your articles help mature our hobby. We look forward to reading about the growth of robotics via your magazine. Thank you. —Robert Mize

*Thank you, Robert, and your son. In my own family, and in many others, playing and working with robots are helping us enjoy learning math, science, and language skills. Perhaps robots will become more commonplace than computers in education. —Mike*

## Plastic is Fantastic

I got a call for papers from the Inventors Society of Southern Nevada for a 'how-to' on plastics for beginners. I dug out your second issue and I believe "Injecting Fantastic Plastic" by Rick Hahn and Tom Durkin would do nicely along with other stuff I will be writing; which will include material selection and manufacturing options for low volume to high volume manufacturing of plastic components. —Wayne Lundberg

*Also see Rick and Tom's quick and easy guide to "Casting Your Own Plastic Gears," in our November 98 Issue. We'll keep publishing the popular fabrication series, working with metals, plastic solder and adhesives, etc. Then see "Vacuumforming on a Shoe String," by Flint Mitchell in RS&T Jan 99.*

## A Late & Lame Issue

Please!!! I'm having a bit of a problem with your latest issue. The first 3-4 issues were fantastic. I loved them and read from cover to cover. I think your content is slipping drastically. How many articles do we need on the Lego MindStorms? The last issue had one, and this issue has two. *Who cares* about Lego MindStorms? The second article wasn't as bad. There were some interesting specs. Keep in mind that this is a *toy*! Anyone requiring these specs probably has more advanced components and mess with instead of hacking a \$200 Lego kit. Show me original Lego combat robots. Show me some of the software that the brick used in combat.

Take a look at the coverage of the FIRST competition. The mention of robots is a paragraph that says they had "vigorous interaction." The rest was about sponsors, location and colorful backdrop. *Who cares?* It didn't have to be technical; show us some robots and tell us why they did or didn't win. Wouldn't a 'H-bridge' tutorial be more important than 6 pages of FIRST competition that only has 1 paragraph which briefly mentions the actual robots themselves?

Your magazine seems to be shifting to target younger people (children) and kit builders. Give us real content. What happened to Mr. Lunt's HC11 series? What about fabrication? I know many amateur robotic engineers would like pointers on vision systems (what camera do I use? How do I get an image from it? How do I process the image once I get it?). Start a navigation series that think the maze series is interesting, and I'd like to see general navigation and collision avoidance stuff. How about motor and sensor applications and interfacing. The wire wrapping was OK. The R/C Servo article was nice. I also like the Combat Robot series. The IR sensor review was nice, but show me real usage for navigation and sample code.

I know you can't please everyone with every paragraph, but you can alienate most people with a late and lame issue. Don't worry about pleasing *me*. I just want you to please the masses. I don't want to lose RS&T. I find it to be a valuable cost-effective resource to my hobby. —Bill Coron

Each of our first issues has been somehow different from the others, to help us discover what readers want. Letters like yours are welcome, even crucial to our success.

Most of what we investigate here is more "grown up" than toys or kits. We're examining "useful" robots, too. In fact, Probotics' CYE just vacuumed our office floors. Articles about fabrication, microcontrollers, vision, navigation and H-Bridges are piled all over our offices, and they are the majority of our forthcoming stories. These tech series have proven most popular, so all future issues will have more content devoted to those kinds of things.

There are over a quarter-million potential readers out there. We need to let prospective advertisers know that dedicated roboticists like you exist in great numbers. Thanks again, Bill, for your helpful critique.

### RS&T Scares Readers

I hope the article "Lego MindStorms: a Technical Perspective" did not discourage too many people from trying Lego's MindStorms kit for robotic experimentation. Mechanically I find the system to be extremely versatile, having hundreds of different types of blocks, beams, gears, shafts, pulleys, wheels, pneumatic components, motors, switches and sensors. One does not need expensive hand tools or access to a machine shop. The sensors are on the primitive side, but they get the job done. Check out the following websites:

RCX Internals at <http://graphics.stanford.edu/~kekoa/rcx/>

RCX Sensor Input Page at [www.plazaeearth.com/usr/gasper/lego.htm](http://www.plazaeearth.com/usr/gasper/lego.htm)

Lugnet users group at [www.lugnet.com/](http://www.lugnet.com/)

There are many alternatives for programming the RCX. I use Visual Basic. C programmers should check out Dave Baum's "Not Quite C" at [enteract.com/~dbaum/nqc](http://enteract.com/~dbaum/nqc).

Another programming system worth checking out is Markus L. Noga's "LegOS" at <http://www.noga.de/legOS/>.

Hopefully, this new information will bring back some of the people who might have been "scared off" by your article, and perhaps encourage a few more to try the Lego MindStorms kit. At less than \$200 it's a great way to get your feet wet in robotics. —Tim Griffin

Thanks Tim,  
Our original MindStorms articles attracted a wide range of letters, from "It's a toy...nobody wants to read about it." to "Thanks for the wonderful coverage...I'll get involved with Lego right now." So perhaps we should run another article written by a die-hard, totally well-informed MindStorms fanatic. Any takers?

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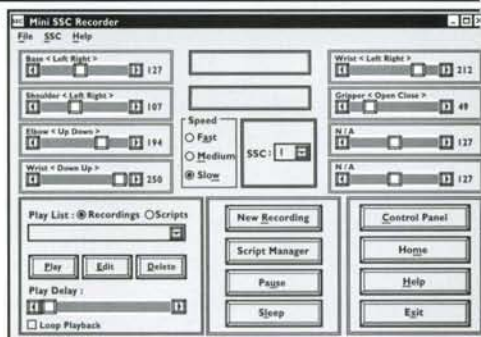
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# INVISIBLE INVASION

*Two-Cents is an anonymous forum for human issues related to robotics*

They are in our cars, our appliances, our homes, and our factories – indeed, they are ubiquitous. We seldom see them but they work hard and untiringly for us. When they do breakdown, which is seldom, we are vexed, perplexed and usually unable to do anything about it except call for help. Now a recent report emanating from the United Nations indicates that this invasion is accelerating.

Despite this prediction, humankind goes blithely about its daily activities, for the most part oblivious to the presence, now and increasingly in the future, of robots.

Beginning with industrial robots in the late 1960's, more and more robots have unobtrusively intruded themselves into the workplace, and increasingly into our homes and environs. There cannot be that many around, you may think.

Ah, but there are! In 1998 Japan, the most highly occupied country on a per worker basis, there were approximately 412,000 robots at work. In its automobile industry, there was one robot for each six human production workers. Overall, in Japan's manufacturing industry, there were 280 robots per 10,000 workers. Meanwhile, in the United States, our ratio in the auto industry was approximately one robot to 19 workers and overall some 44 robots per 10,000 workers.

With this superior investment in robotics, Japan has seen its economy grow rapidly, to the point at which it is second only to the US in the world. Of course, we all know about robots in the industrial sector. They are already there, albeit in numbers we might not have realized. "So where is the invasion heading next?" you ask.

Answer: Your home (vacuuming), your lawn (mowing), and your hospital (surgical assistance), to name just a few places and activities of personal interest to you.

Service robots, those that perform a task that free up some of your time or perform a precision operation which takes the shakes, out of a surgeon's hands, are already here and more variants are coming soon. To give some scope to the

magnitude of this explosion in robotics, the UN study forecasts the installation of 24,000 major service robots and the sale of as many as 500,000 vacuum cleaning robots alone in the period 1999-2002. These are examples of where the science and technology of

robotics is headed, and where the next flood of invasion will take place.

The ranks of the invasion are not of flesh and blood but of metal and silicon. Tireless and unforgiving, this new force does not answer to human control, it will drive our economy, and our society, and ultimately, our humanity.

Is your company ready for it? Your government? Are YOU ready for it?

**Unfeeling, this force  
does not answer to human control;  
but it will drive our economy,  
our society, and then our humanity.**

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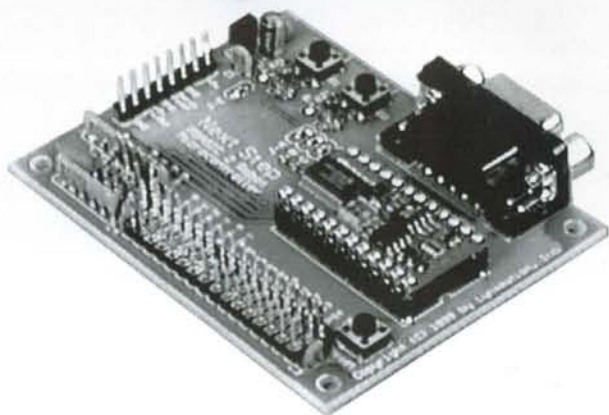
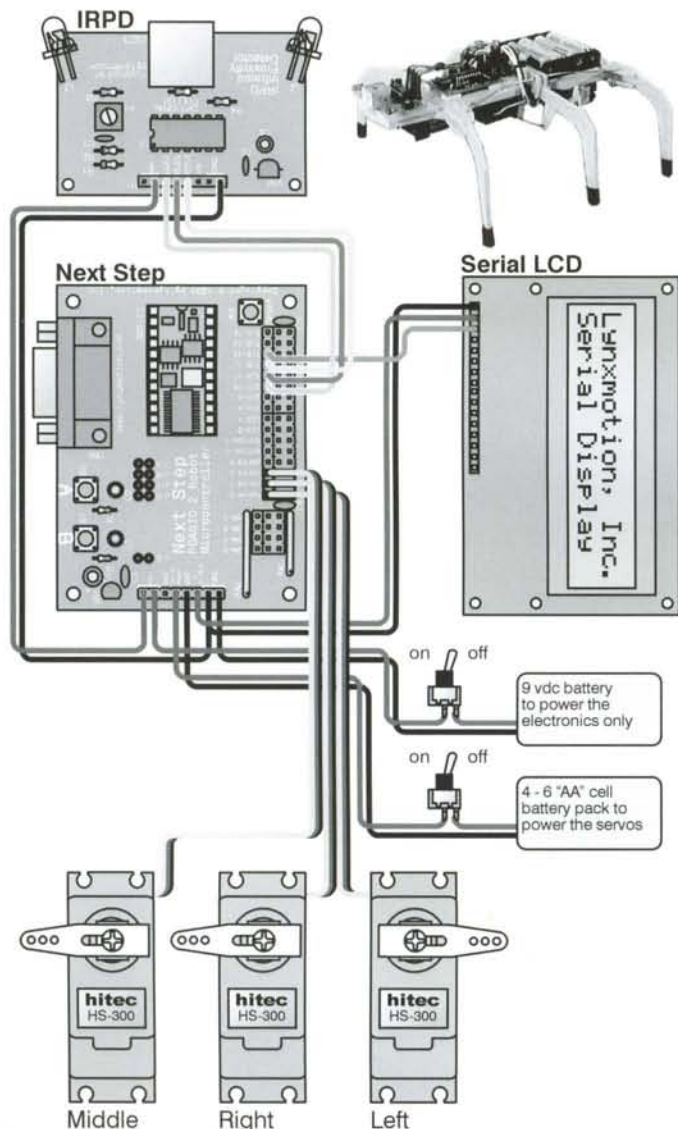
## The Next Step Microcontroller Kit

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- Powering options for different situations.
- 16 I/O lines, plenty of room for expansion.
- Many modular sensor add-ons ready to go.
- It has never been easier to control an advanced sophisticated small autonomous robot.

### Next Step Microcontroller Information

The Next Step Micro is a BASIC Stamp 2 based microcontroller that has been specifically designed for autonomous robot control. The illustration below shows a typical setup for controlling a simple 3 servo walking robot. The users manual illustrates several different configurations. The microcontroller has many features that the robot builder will find useful.

### Typical Setup for a 3 Servo Walker



**NEXT STEP MICROCONTROLLER**

### Features

The Next Step has all of the features of the popular BASIC Stamp 2 IC, such as the ease of use, and the simple straight forward programming language. However, the Next Step has added some new features specific to the robot builders needs.

- 16 I/O lines, up to 4 servos and 4 bumper switches share the first 4 I/O lines by using a little known method of multiplexing.
- Powering options allow the BASIC Stamp to be powered with the servo power supply or separately from it's own supply
- Two Buttons and two LEDs make a simple user interface to allow choosing which program, or subroutine to run, or to allow certain parameters to be altered while the program is running.
- DB9 plug allows easy connection to a PC's serial port for a quick program download.
- High quality PC board with solder mask means quick, easy and trouble free soldering.

### How does it work?

Programming the Next Step is extremely easy. Simply plug the cable from the PC's serial port into the micro. Run the Windows editor and type in, or load an example BASIC program. Click on Run, and the program is downloaded to the micro, and automatically begins running. You may remove the programming cable for complete autonomous operation. The code is stored in an EEPROM, and therefore protected from power loss. If you want to change the program you may download new code at any time. The micro will stop, accept the new code, and then immediately begin running the new code. It's that easy.

### Ordering Information

First time users of the Next Step Micro will need a DB9 straight through cable and instructional literature. This documentation can be found at the Parallax web page, and is free to download and print. The BSP-01 BASIC Stamp Programming Pack includes the printed manual and cables. The book, Prog. and Cust. the BASIC Stamp Computer is a great tutor.

Part No.	Description	Price
NS-01	Next Step Microcontroller	\$40.00
BS2-01	BASIC Stamp 2 IC -or-	\$49.00
BSSX-01	BASIC Stamp 2 SX IC	\$59.00
BSP-01	BASIC Stamp Programming Pack	\$99.00
CK-01	Connector Kit (for making jumpers)	\$23.00
<b>- Works well with these components -</b>		
SSC-01	Serial Servo Controller	\$44.00
SLM-01	Serial LCD Display	\$49.00
IRPD-01	Infrared Proximity Detector Kit	\$30.00
TRA-01	Tracker Line Following Sensor Kit	\$20.00
DHB-01	Dual H-Bridge Motor Driver Kit	\$30.00
<b>- Other useful documentation -</b>		
BSB-01	Prog. & Cust. the BASIC Stamp Comp	\$35.00
BSP-01	Mobile Robots Book Second Edition	\$32.00

Note: BASIC Stamp and PBASIC are trademarks of Parallax Inc.

# CLOSED CIRCUIT

## Readers Helping Readers

### Marc's Macintosh Robotics Resources

I saw the letter in the Sixth Issue of *Robot Science & Technology* where Paul Lenoue was looking for Macintosh-based applications for programming and interfacing with robots. I have been digging for the same thing for a while and this is some of what I have found so far.

For Lego robotics there are two Macintosh-based applications that come from Lego. The original robotics program is the Lego Dacta Control Lab. It controls the Lego motors and sensors with the aid of a Serial Interface Box that connects to the Mac's serial port. Logo is the language that is used for this software. The Control Lab Building Sets can be ordered from Pitsco.

Software for programming the Lego MindStorms RCX is also available from Pitsco. This is the RoboLab software, a customized version of Labview. This is a much more powerful programming environment than the MindStorms software. This software is very exciting because it allows for some very complicated algorithms to be developed. Among other things, user defined variables are available and structures can be developed. This goes a long way to addressing the inadequacies in the MindStorms that Tak Auyeung noted in his review article (see RS&T Oct 99).

A free program is available that allows RoboLab to drive Lego motors and sensors through the original Serial Interface Box. This is called Engineer and is available at <http://ldaps.ivv.nasa.gov/LEGOEngineer/>. It was developed at Tufts University.

Another software package (that does not come from Lego) is available that can be used to drive the Lego motors and sensors. It is called Hyperbot. It connects to the Mac serial port through a custom interface. The software has a very nice and easy-to-learn interface that is great for students 6 and older. See [hyperbot.com](http://hyperbot.com).

Two other software packages are available for interfacing with robots using the Hyperbot interface. They are at [terrapiologo.com/logo/logoplus.htm](http://terrapiologo.com/logo/logoplus.htm) and [truebasic.com/editions.html](http://truebasic.com/editions.html).

For more hard-core Macintosh robotics enthusiasts there are several resources for programming Microchip's wildly popular PIC family of single-chip microcontrollers. There are two different compilers. First there is MacPIC, a shareware compiler that programs a large range of PIC chips. As a novice I can't offer the most complete listing of what is supported but more information can be found at [MacRobotics.com/MacPIC.html](http://MacRobotics.com/MacPIC.html). A lot of information can be found at [macrobotics.com](http://macrobotics.com) that will aid in finding all the components that are needed to get a development system running on a Mac.

Another PIC development system is available at [execpc.com/~fdeck/mac/](http://execpc.com/~fdeck/mac/). It provides a PIC compiler and plans to build a programmer to connect a Mac serial port. This is a complete development system.

A critical resource needed for talking to devices through a serial port is at [mindspring.com/~jc1/serial/](http://mindspring.com/~jc1/serial/).

The MacTron Mailing List is another resource available for Macintosh robotics enthusiasts. This is a mailing list for people interested in doing robotics, embedded software and other related things with their Macs. The MacTron home page is at [WildRice.com/MacTron/](http://WildRice.com/MacTron/).

I hope this helps a little bit.

-Marc Jensen

*Thanks, Marc, for helping our Macintosh brothers. It's our intent to make robotics accessible to computers of every color. Now, where are you Linux guys?*

ClosedCircuit is our reader-to-reader forum. Have a hard question? Have an easy answer? Email [Editor@RobotMag.com](mailto:Editor@RobotMag.com) with "ClosedCircuit" in the subject line.

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# LEARNING FROM MARS

Bringing Martian Technology Down to Earth

by Tak Auyeung

After all the hype associated with the latest Mars mission, many disappointed people are starting to forget about the machines we shot at the Martians.

Besides, what does it have to do with earthly robotic projects, anyway? After all, who wants to build a robot to dig up dirt and analyze for climatic patterns over the past billion years in your backyard!

As it turns out, the Mars Polar Lander is a robot with many ideas and technologies applicable to earth-bound utility robots and amateur robots running around the backyards and houses of RS&T readers and our friends. To refresh your memory about the Mars Polar Lander, visit the extensive Jet Propulsion Laboratory website at <http://marslanding.jpl.nasa.gov>.

The Lander uses many instruments to sense the surroundings. Of particular interest is the Surface Stereo Imager (SSI) on the Lander. According to JPL, the SSI is similar to the imager on the previous (and successful) Mars Pathfinder.

This device serves three main purposes: imaging, ranging and analyzing. The imaging task is handled by the imaging sensor that records high-resolution still images. Since the SSI has two "eyes" (optical lenses), the differences between the image captured from each of the eyes can be analyzed to provide range information.

Last but not least, the SSI image sensor is sensitive to a wide spectrum of light, from visible to near infrared. The SSI has an array of built-in filters to help isolate specific wavelengths in an image to compute the amounts of water and dust in the atmosphere.

An earth-based robot could borrow many of the features of the SSI. Consider the design of a rescue robot deployed in a hostile environment (for example, seismic, toxic, radioactive or infectious sites). After an earthquake or explosion, it is unlikely that any existing maps or floor plans will be useful for navigation. The ranging ability of the SSI could map the environment and report the damage, and also support automatic search navigation. Human operators can use the imaging feature to remotely view the scene.

The wide-spectrum sensors and filters would need to be extended to far infrared. The ability to detect and isolate far infrared allows the imager to pinpoint body-temperature objects that may be survivors.

The Lander's robotic "scooping" arm, combined with the Thermal and Evolved Gas Analyzer (TEGA) can be very helpful as well. After a toxic, bio-toxic or radioactive accident, it is important to assess the extent and type of contamination. The robotic arm, with its own on-scoop camera, would allow an operator to accurately scoop up samples.

The samples are then analyzed by the TEGA. The TEGA consists of single-use ovens and a tunable diode laser spectrometer. The ovens heat up the sample until it is partially vaporized. The laser then shoots beams of light of known frequencies through the vapor.

Note that a laser can only emit light at one frequency at a time. Depending on the composition of vapor, unique wavelengths are absorbed. The absorbencies at different frequencies indicate types and quantities of vapor components.

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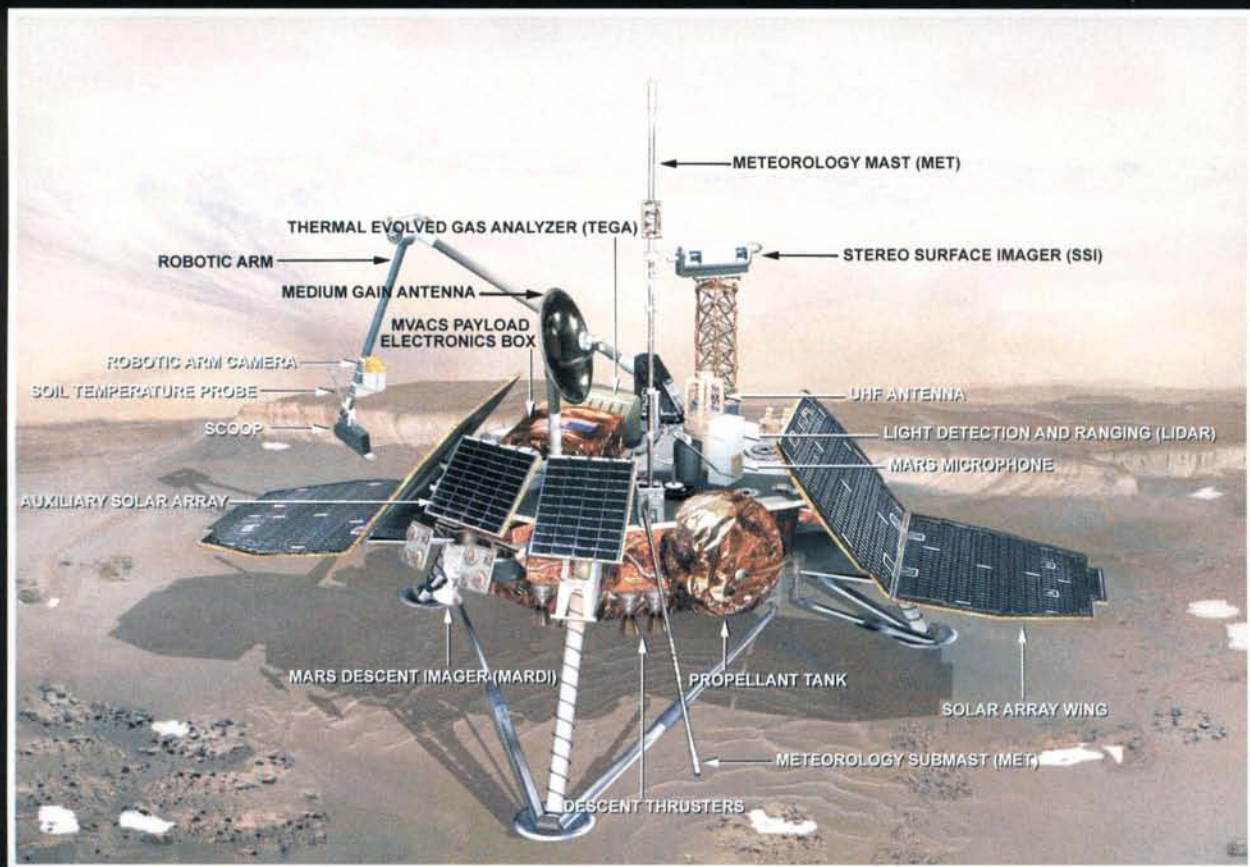
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For toxic chemical applications, scientists would need to modify the TEGA to analyze for specific toxins and harmful elements, but an on-board analyzer would save a lot of transport time and prevent contaminating human emergency crews.

The power source of the Lander is also very earthly (perhaps *sunny* is a better word). Although Mars receives less sunlight than Earth, the design of the solar panels of the Lander still manages to output 200 W of power. Back here on Earth, an outdoor robot should be able to capture some solar energy, at least as a secondary or backup source of energy.

The benefits of solar panels apply to any outdoor robot, on any planet: they are light weight, cordless, and inherently rechargeable.



Art courtesy NASA/JPL/CalTech

Okay, very few of us will ever build a Mars explorer, and few will build a rescue robot. So, what do the rest of us (without the budget to acquire cool gadgets like the SSI and TEGA) gain from studying the Lander technology?

Imaging and ranging are certainly two of the most important senses of a mobile robot. Fortunately, both can be done with a budget that most taxpayers can afford (with our *after-tax* money).

The options for imaging are endless these days. Very small cameras with NTSC output are common and some cost less than \$100 US. Off-the-shelf NTSC video radio transmitters and receivers can broadcast the robot's view.

As for ranging, the Sharp GP2D05 and GP2D02 sensors provide inexpensive options at about \$20 US. (Please refer to

Steve Richards' article on how to interface to the sensors, in RS&T Number Six.) Unlike the SSI, however, the GP2D05 and GP2D02 can only range a "point" instead of an entire scene. Mechanical scanning is required to acquire a depth-range "picture."

On-robot image processing, on the other hand, remains somewhat more challenging. Advances in digital cameras have motivated the design and mass production of charge-couple devices (CCDs) with on-chip digital interfaces, such as the Sony ICX098. You can even buy board-level products including the lens, CCD and digital interface, such as the Sony MCB120. However, interfacing such CCDs and camera boards still requires significant knowledge of electronics circuit design as well as low-level software device drivers. Once an image is captured, the analysis often involves com-

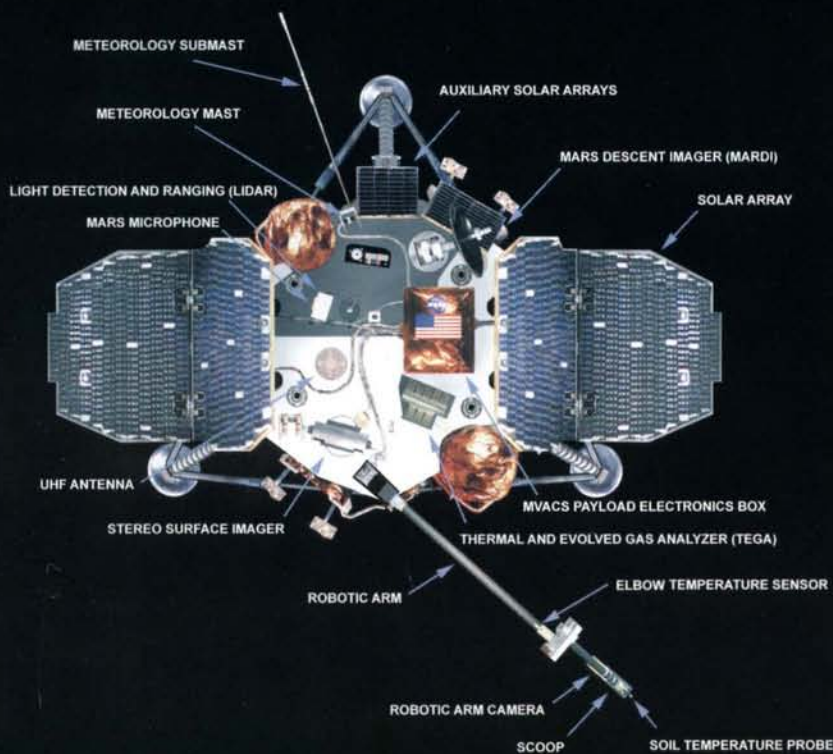
plex programming. Consequently, although the cost of components is inexpensive, it requires much expertise to design and assemble an on-robot vision system.

For those who are not thwarted yet <http://pages.zoom.co.uk/andyc> presents a relatively simple project to get computer vision using very inexpensive components. And, of course, robot vision is in RS&T's editorial plans

Anyone who has built mobile robots probably wishes the robots had arms that actually *do* something.

Various manufacturers have introduced affordable robot arm kits since the 1980s. Two design limitations keep these robot arms stationary and useful for very few practical applications outside education. First of all, the arm-

### MARS POLAR LANDER SEEN FROM ABOVE



as purchased, provide no feedback about their current positions. This makes it impossible to position an arm really accurately. Secondly, even if movements were accurately controlled, there is no built-in way to know how far to reach for objects.

While the Lander design does not have grippers (there was no intention to *abduct* Martians), it does use a robotic arm to scoop dirt from the surface. The Lander uses a "scoop-cam" to help control the arm. An amateur robot can autonomously control an arm with less expensive components. First of all, object detection can be accomplished by a two-dimensional range scan using a range sensor, such as the Sharp GP2D02, mounted on a tilt-and-swivel head. No doubt, the acquisition is going to be slow as the head needs to sweep from

side to side. The movement of arm joints can be encoded by encoder disks.

(Quadrature encoding and decoding will be discussed in the next issue of RS&T.) Proximity sensors can be mounted at the gripper for the final grip confirmation.

As an energy source, small solar panels are readily available. A 6" by 6" solar panel, capable of producing 0.5 Watt, costs about \$5 US at surplus stores. While most mobile robots require several Watts to move, the solar panels can charge a battery when the robot is stationary, then discharge the battery when the robot moves. Of course, a 6" by 6" 0.5 W solar panel is no match for the Lander's 200 W solar panel. On the plus side, we're not going to transmit data between planets. Conveniently, a

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As we patiently wait for our Martian friends to repair the Lander, we can design and build robots *inspired* by the Lander and the Pathfinder missions.

Readers are invited to send details and photos of Mars project robots.

RS&T

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## Robot Kits

### Spider Walking IR AVOIDER Robot #3-299 \$69.95



Futuristic & maneuverable 6-legged walker with IR for object avoidance. Dual motor drive, front mounted sensor. 13 cm L x 13 W x 10 H. No soldering required, needs 2 AA & one 9V cell.

### Cybug Robot Kit #3-466 \$49.95

Cybug has touch & light sensors to exhibit active & interesting behaviors. Printed circuit board & 2 DC motors! 12 cm L x 10 W x 4 H. Soldering and one 9V cell required. Machine or living organism?



### Cybug Predator/Prey Add-on #3-501 \$32.95

Build & attach the predator & prey circuits to two of your Cybugs & then let them roam wild! The Predator will sense the L.R. signal from the Prey & hunt it down!

### Cybug Hunger Instinct Add-on #3-503 \$29.95

The hunger circuit board lets your Cybug sense its battery level and seek light when "hungry". Includes notes for making a recharging station (requires other parts) so your Cybug can recharge itself!

### SolarFly Robot Kit #3-529 \$59.95

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Powered by the Sun! The SolarFly continually seeks the brightest object it sees. Twin feelers help navigate around obstacles. It even has short-term memory about objects it contacts! The long vertical antennae can draw energy from other sources

such as the Sunflower Power Plant or your feeding stations described in the kit. Assembles with basic tools, requires soldering. Add a swarm to your CYBUG farm!

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### LEGO® Robotics Invention System V1.5\* #3-699 \$199.99



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- MindStorms RCX IR Remote Control #3-546 \$24.99
- MindStorms Motor 3-pack #3-552 \$49.99
- MindStorms Touch Sensor #3-347 \$17.99
- MindStorms Light Sensor #3-329 \$29.99
- MindStorms Rotation Sensor #3-544 \$24.99
- MindStorms Temperature Sensor #3-516 \$29.99

### LEGO Robotics Discovery System\* #3-521 \$149.99

Bring your Lego creations to life! Scout computer is fully programmable from the on-board LCD command center. Create different behaviors with the touch of a button - no external programming from a computer required! With built-in light sensor, two inputs, two outputs, LED feedback lights, and IR communications plus 2 motors, 2 touch sensors, manual and over 380 LEGO pieces.

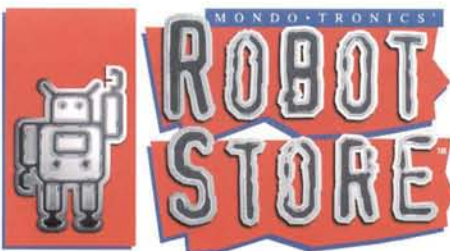


### LEGO Droid Development Kit\* #3-589 \$99.99



The Droid Developer Kit is your introduction to robot building. Make your own R2-D2, battle droids and other robots from Star Wars, then experiment with different configurations to create your own droid series.

Includes the Micro-Scout Lego computer with built-in light sensor, built-in motor and seven built-in behaviors plus over 650 Lego pieces.



### WAO G Programmable Robot #3-477 \$84.95



A new edition of a sophisticated, full function robot kit. 2 motors, programmable "fuzzy logic" brain, 26 button keypad, sensor arms for collision or edge detection, Moves in all directions, performs if-then decisions based on sensor inputs and "fuzzy" membership rules, even do-loops! Requires 3 AA & one 9V battery. No soldering required. Great intro to robot programming.

### Descartes Robot Kit #3-710 \$229.00

Descartes is based on a dual processor architecture. Features four true 8-bit analog to digital (A/D) converters, four CdS light sensors, LEDs, shaft encoders, thermistor, touch switches and a speaker. Demonstrate nocturnal/diurnal behavior, phototropism/photophobia, non-contact object detection, motion detection, dead reckoning and more! *Programmable from your PC.*



### Rug Warrior Pro Deluxe Kit #3-406 \$595.00



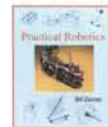
A complete, serious research robot platform from MIT. With all hardware, C software, 68HC11 CPU, memory, sensors, wheels, motors, chassis, instructions & more. 18 cm dia. The ideal companion kit to the Mobile Robots book (3-613, below). *Mac & PC compatible!*

### Mobile Robots 2nd Ed. #3-613 \$39.95

From MIT, a complete guide to designing & building robots: hardware, software, sensors, motors, "subsumption" software. 336 pages, illust. A must for all roboticists.



### Practical Robotics #3-506 \$39.95



If you ask "Where do I start?" the answer is "HERE!" Bill Davies shares years of robotics experience, covering all aspects: tools, techniques, components, sensors, soldering, etc... 330 pages with a fine index.

### Build Your Own Underwater Robot #3-418 \$29.95

Dive in to underwater robotics! The authors provide dozens of hands-on experiments using readily available parts. 148 pages. Great illustrations and a lot of fun!



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International Orders Welcome! See website for details.

## BASIC Stamp®

### Stamp One Starter Pack #3-444 \$99.00

A complete starter set: Stamp Software, manual, cable, a Stamp 1 (see right), and a BS-1 Carrier Board with prototyping area & connector for the programming cable. A great value!



### Stamp Two Starter Pack #3-439 \$148.00

Everything needed to move with the Stamp 2: All of the items in the Stamp One Starter but with a Stamp 2 and BS-2 Carrier instead. Monstrous power!

### Stamp Two SX Starter Pack #3-647 \$159.00

New! Powered by Scenix microchip. Runs at 50 MHz (2.5 times faster than the standard Stamp 2), and has eight 2KB program spaces. A powerful brain for your next robot!

### Mini SSC 2 & Servo Bonus Pack #3-436 \$129.95



Control up to 8 servos via one serial line. Talk to it from any PC, Mac, Stamp, etc... Plus, daisy chain up to 32 together to control up to 255 servos. Includes six Hitec-300B servos!

## Robot Legs, Robot Arms

### 5 Axis Robotic Arm Kit #3-366 \$195.00

Fast, repeatable, and controlled from your computer serial port! Can lift over 160 grams. Control swivel, shoulder, elbow, wrist, and gripper. Mini SSC 2 board & DOS software included!



### Hexapod Walker Kit #3-434 \$150.00



Three servos provide full directional walking. Program in Basic from your PC. All hardware, electronics, software & instructions included. Over 20 cm long. Requires soldering.

### Quadrapod Walker Kit #3-670 \$295.00

Walks forward, backwards and turns left or right. Includes precut body and leg panels, mechanical hardware, 8 servos and assembly manual. Add your own servo controller (Mini SSC, ASC-16, etc.), microcomputer and sensors for full autonomous operation.



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



A heavy duty walking platform - over 35 cm (13 in) long! 12 servos give full control & major strength. Add your own servo controller (Mini SSC, ASC-16, etc.), a microcomputer (Stamp2, BOTBoard, etc.) & sensors for advanced projects!

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Sleek silver wings flap using only 6 cm of Muscle Wire! Variable speed up to 36 flaps/minute. 15 cm tall. With circuit board, all parts & instructions. Requires soldering & 2 AA cells.

An ideal introduction to Muscle Wires.

## BattleBots

Jan 29 on Pay Per View

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

See the destruction wrought in Las Vegas.

## Wireless Symposium Portable by Design

Feb 22 - 25, San Jose Convention Center

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

Visit Lemos International at Booth 1527

## 14<sup>th</sup> Annual Student Robotic Challenge

Robotics International of the Society of Manufacturing Engineers

March 19 - 20 at Robert Morris College in Pittsburgh

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

14 events, including 150 pound sumo, simulation, maze and lunar search.

See our Journey Robot stories beginning on Page 30.

## Fuji Soft ABC Robot Sumo Tournament

March 28, Exploratorium, San Francisco

March 30, UC Riverside, Los Angeles

Hakkeyoi Nokotta!

## FIRST Robotics Competition

[www.usfirst.org](http://www.usfirst.org)

An exciting national engineering contest for high school student teams, showcased in RS&T April 99 and RS&T Oct 99.

March 9 - 11, Eastern Michigan University, Ypsilanti, MI

March 9 - 11, Kennedy Space Center

March 16 - 18, Rutgers University

March 16 - 18, Houston Astro Arena Complex

March 23 - 25, Northwestern University, Evanston, IL

March 23 - 25, Drexel University, Philadelphia

March 30 - April 1 NASA Ames, San Jose

March 30 - April 1 Meadows Music Theater, Hartford, CT

April 6 - 8 National Championship, EPCOT, Orlando

## Seventh Annual Trinity College Fire-Fighting Home Robot Contest

April 16

[www.trincoll.edu/~robot](http://www.trincoll.edu/~robot)

Jake Mendelsohn's original. The national topper to regionals in Seattle, Dallas, Philadelphia, Tel Aviv and Calgary.

See RS&T Premier Issue for tips.

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## Northwest Robot Sumo Tournament

May 20 [www.SineRobotics.com](http://www.SineRobotics.com)

Edmunds Community College, WA

All sumo robots invited, open to the public. Hosted by Bill Harrison of Sine Robotics.

## BEAM/WCRG Millennium Games

June 9-11 [www.robotgames.com](http://www.robotgames.com)

SAIT Campus, Calgary, Alberta

Solar, Autonomous, RC, Sumo, Walking, Fire-fighting, micromouse and more. Speakers, Mark Tilden, Bill Harrison, Craig Maynard, Mark Hillier, Dave Hrynkiw, Mike Munro and Hilton Delivera. Plus an educator's course hosted by Parallax.

Email your events to [Editor@RobotMag.com](mailto:Editor@RobotMag.com)

# events

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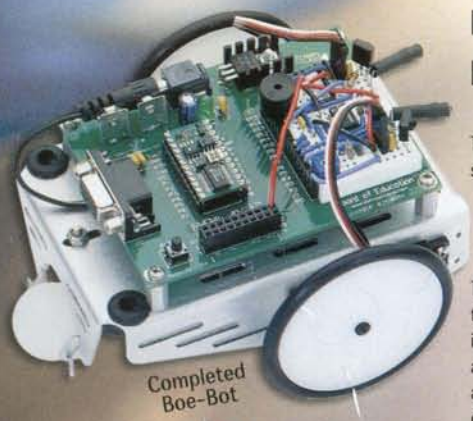
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Completed Boe-Bot

## Introducing the Boe-Bot: Mobilize Your BASIC Stamp<sup>®</sup> and Board of Education

The Boe-Bot is a BASIC Stamp II and Board of Education (BoE) mounted on a rolling aluminum chassis. The BoE's breadboard is used for your robotic projects. The kit requires about one hour to build using a small screwdriver, box-end wrench and diagonal cutters. The Boe-Bot was created for our Stamps in Class program (<http://www.stampsinclass.com>). The 70-page Robotics text is loaded with projects ranging from basic movement to object detection and light following.

The Boe-Bot Full Kit includes the robot shown to the left (unassembled) with text and all the electronic components needed for roaming, object detection / avoidance with infrared, and light following. LEDs and piezospeaker provide light and sound feedback. With some advanced programming and a few components the Boe-Bot could follow a line, solve a maze, or extinguish a small fire. PBASIC is an I/O-oriented language with a command set that makes it easy to interface the BASIC Stamp to other components.



Robotics text

# BOE BOT

### BASIC Stamp Boe-Bot Full Kit #28132 - \$199

Boe-Bot, Board of Education, BASIC Stamp II, BASIC Stamp Manual Version 1.9, Robotics Text and components

### Robotics Parts Kit #28124 - \$99

Order this kit if you already have a BASIC Stamp II module and a Board of Education.

### Robotics Text

Free download from our educational website at <http://www.stampsinclass.com> or order a printed version #28126 - \$19.00

To order call Parallax toll-free 888.512.1024 8 a.m. to 5 p.m. PST



Bread Board AppMod



## GrowBot Upgrade:

Mount Your PCB on the Boe-Bot's Metal Chassis for Improved Performance!

The Boe-Bot chassis was designed to accommodate the GrowBot's printed circuit board. If you've already got a GrowBot and you want to mount it on the metal chassis, order the GrowBot Upgrade Kit. The chassis will hold the servos squarely in position and provide a solid base for any additional construction you do on top of the GrowBot. Plug the optional AppMod onto your GrowBot and then you can build the Robotics projects using the BASIC Stamp's leftover I/O pins.

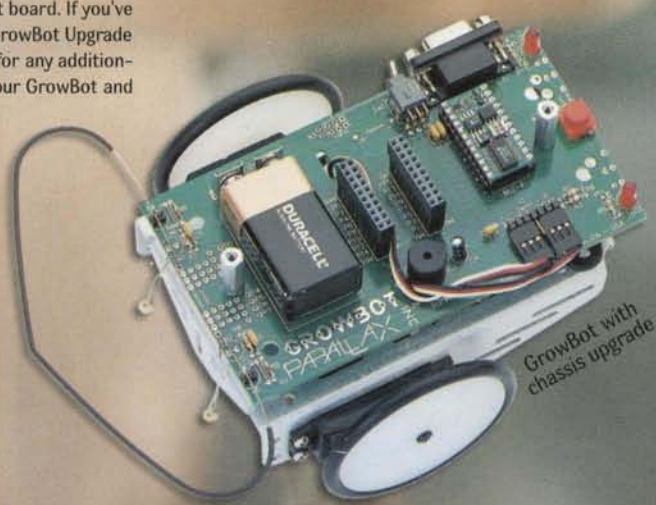
### GrowBot Upgrade Kit

#29101 - \$49 Includes chassis, screws, standoffs, tail wheel, and battery pack, you'll reuse the GrowBot's PCB, servos and wheels.

### Bread Board AppMod

#29114 - \$29 AppMod: Module brings BASIC Stamp I/O pins, Vss, and Vdd connections to the perimeter of breadboard.

More info? Visit us online at [www.parallaxinc.com](http://www.parallaxinc.com) or [www.stampsinclass.com](http://www.stampsinclass.com)



GrowBot with chassis upgrade

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