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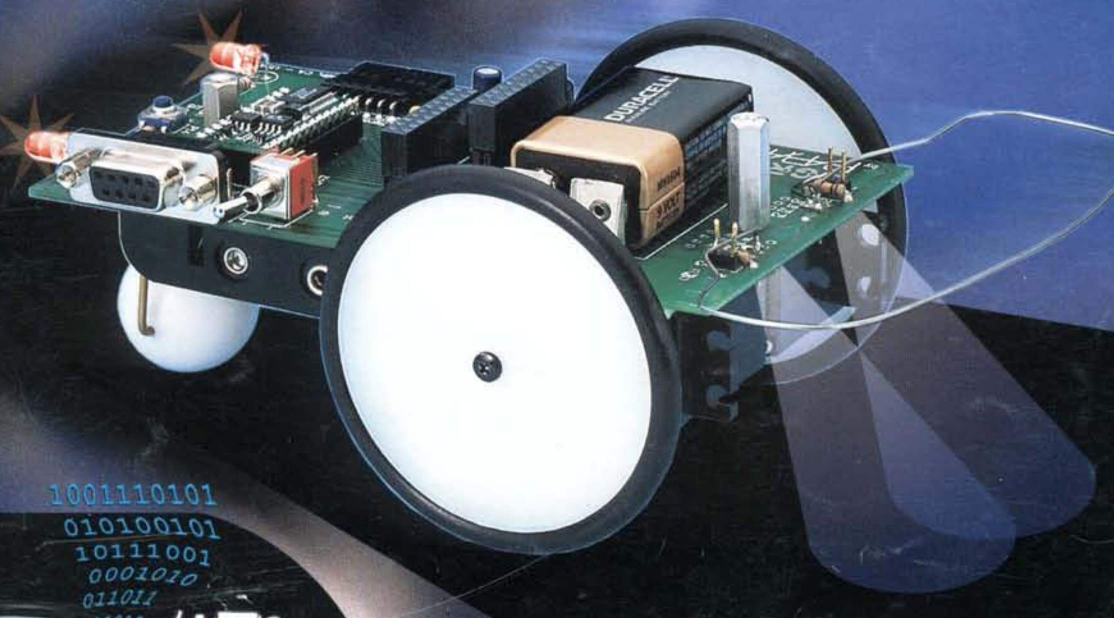
OUR FOURTH ISSUE • JANUARY 1999

a GROWING Robot



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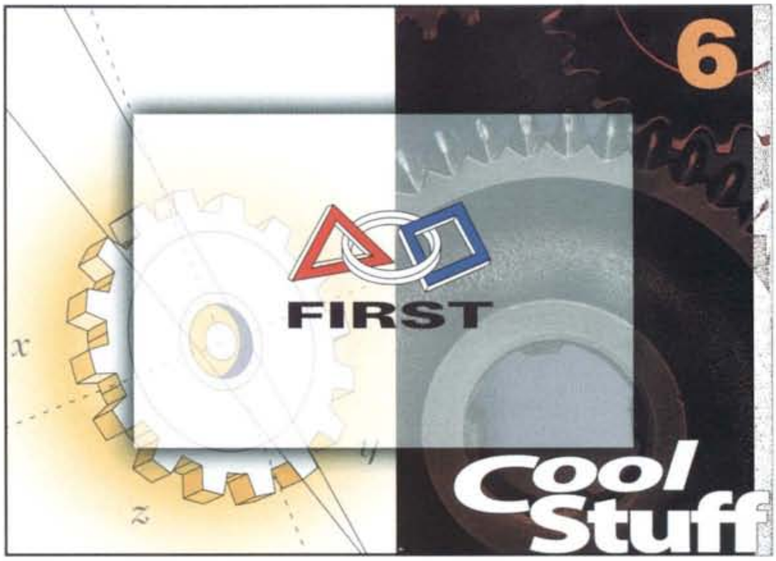
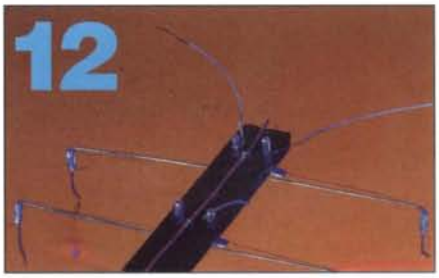


by Michael Bastoni and RS&T staff

Sponsored by the FIRST Foundation, this tournament teaches young people that high-tech is cool, and learning is fun.

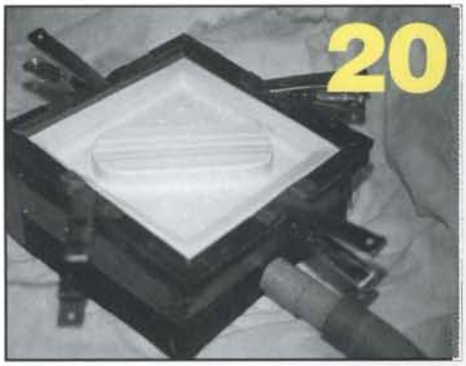
Building an Inexpensive Insectoid Robot



by James M. Conrad, PhD, Ericsson, Inc., and Wayne Brown, Dynalloy, Inc.

Nitinol wire expands and contracts with the application of heat, roughly emulating the operation of a muscle. The fascinating alloy has spawned a family of small, inexpensive, and educational insectoid robots.

Vacuforming on a Shoestring



by Flint Mitchell

Clothe your robot using this inexpensive, fascinating method of molding plastic to fit your bot's bod.

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Cover Design: Parallax's new GrowBot, illustrated by Jen Jacobs, courtesy of Parallax Inc. For more about this bot, see page 30.

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Floyd C. Painter

Technical Editor
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Art & Design
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Contributing Editors
John Piccirillo, PhD
Kristine Wills, MD

Contributors
Tak Auyeung, PhD
Michael Bastoni
Carlo Bertocchini
Wayne Brown
James Conrad, PhD
The Iconoclast
Flint Mitchell

Writers, see page 54

Advertisers, see page 51
916.632.1000
publisher@robotmag.com

Distributors call
916.632.1000

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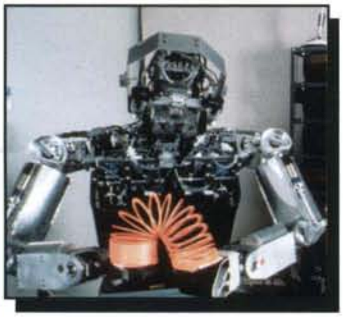
Our Mission: to immerse readers in 21st century robotics technology with in-depth reports on real robots, and through hands-on adventures with home, classroom, and sport robotics.

from the publisher

Sometimes it's Rocket Science, sometimes it's not. Some of our articles are hands-on, a few are academic, and many are beginner stuff. Most readers have asked us to continue this mix. Were some articles in our November issue too cerebral? Send us your feedback.

Holidays are for Having Fun, so we replaced this month's centerfold with a 21st Century Robot Showcase starting on page 25. Readers of all ages and all skill levels will find robots and robot kits to fit all budgets. We couldn't show *all* commercially available robots, of course, but this is a good start.

We Need Correspondents who can write well and photograph close-up, to cover events around the world. Our calendar of events on page 64 is just a sampling of the events that are regularly worthy of your attention. FIRST events, AROB '99, and the Fort Wayne Robot Games look particularly interesting.



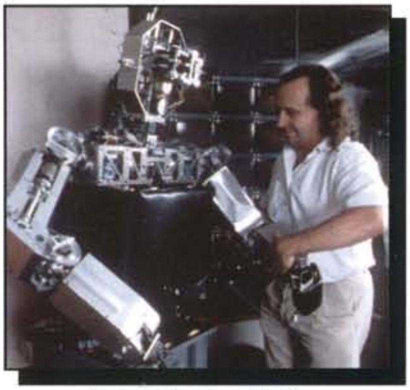
New Robotics Businesses are sprouting up all over. To place an effective but budget-friendly classified or display ad, call me at (916) 632-1000.

Bookstore Sales were Unexpectedly Phenomenal, so we'll continue moving onto newsstands. Potential distributors should e-mail Publisher@RobotMag.com.

The 10th All-Japan Robot Sumo Tournament will visit San Francisco and Los Angeles on March 22nd and 25th respectively. Five self-controlled and five remote control Sumo-bots are flying in, and are looking for some Americans to battle. No more details available at press time. More in our February issue, and at www.RobotMag.com.

Cog Watchers Delight. Our favorite humanoid research platform at MIT's AI Lab has two arms now, and is smart enough to rotate a hand crank or play with a Slinky. (Think about the difficulties of quickly adjusting to emerging harmonic frequencies.) *Cog* also has gained some surprising vision behaviors, which RS&T will bring you soon.

During a recent presentation, Prof. Rod Brooks was asked, "Why haven't you equipped *Cog* with legs?" Brooks looked a little surprised at the question. "Why haven't we added *legs?*" he exclaimed with a little smile. "It took us *years* to get *this* far!" As the publisher of RS&T, I know the feeling, Rod.



Rodney Brooks with **Cog**.
Photos by Donna Coveney, MIT.

Michael A. Greene

PS Special thanks to Julie Knudsen and Sam Toll for the excellent layout of this issue.

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FIRST Robotics

Partnering Industry and Youth

Competitive Environment Involves Young People in Engineering and Science

by Michael Bastoni and RS&T Staff

Imagine yourself as part of a tumultuous crowd of ten thousand screaming fans, decked out in team colors and cheering for your squad. Cheerleaders, mascots, banners waving, elated fans surging and urging the players on. Your high school team scores and you respond with a roar of approval, following the lead of leaping, bounding cheerleaders. The referee settles a dispute, and you settle down to watch the keen competition until the next score, when the madness begins again. This is typical of the hysteria that occurs on countless fields and courts of sport combat across the country. The student body, family members and friends exhort their athletes on to higher achievements, and each success meets with resounding approval. This crush of humanity you are part of must be watching a championship game during the state basketball tournament, right? Or could it be football delirium as the home team leads a heavily favored opponent going into the last minute of play?

A crowd of about 10,000 people cheer in front of the main stage at the 1998 FIRST championship tournament at Walt Disney's EPCOT Center in Orlando, Florida. Photo by Dia Stolnitz.

Neither is the case, and what may be most surprising is that the athletes performing on the playing surface are not human, but robots. They are carefully designed, unique and original radio-controlled robots built by teams of high school students. The ten thousand enthusiastic spectators are real, and so is their enthusiasm. They were attending the 1998 national finals of the robotics competition sponsored by the FIRST Foundation (For Inspiration and Recognition of Science and Technology). The finals were held at Walt Disney World's EPCOT Center in Orlando, Florida last April. This is the story of FIRST, and some of the people who made that exciting scenario possible.

What is FIRST?

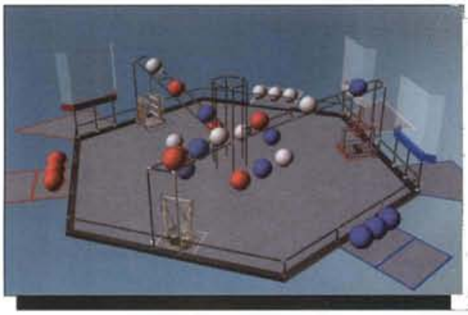
FIRST is a non-profit organization founded in 1989 by inventor and entrepreneur Dean Kamen, and it is based in Manchester, New Hampshire. Kamen recognized that American high school students did not rank high in math and science compared to their counterparts in other industrialized societies. To help improve the situation, he created FIRST to cultivate an awareness and appreciation of engineering and technology in young people. Over the years, Kamen has been aided in his efforts by Woodie Flowers, PhD, Director of the New Products Program at the Massachusetts Institute of Technology. Kamen and Flowers created an engineering contest that provides young people with the opportunity to experience first-hand the excitement and possibilities of the world of science and technology. It is a tournament in which teams of students, mentored by professionals, design and build highly specialized robots that compete against each other. The rules of the competition change each year, challenging the intelligence, imagination and ingenuity of students and mentors alike. The robots then become extensions of massive team efforts, and controlled by their eager young inventors, engage other robots in complex competitive sce-

A cheerleading squad responds to a score during the national championship tournament at EPCOT. Photo courtesy FIRST Foundation.

Woodie Flowers, PhD, a co-founder of FIRST, sponsors a coveted award each year for the individual participating in the FIRST tournament who best demonstrates excellence in teaching science, math and creative design. Here he demonstrates his excellent choreography, cheerleading and directorial talents.

narios. Each team's robot must outperform other robots, not overpower them. In this sense, the competition is one of problem-solving using intellect, imagination and ingenuity, the antithesis of those athletic events that glorify brawn and physical superiority. The lesson demonstrated effectively to these young people is that science and technology can be as exciting as any sporting event.

The typical FIRST team is advised by scientists, corporate engineers and graduate students. These mentors assist students in meeting the engineering challenges. The students are provided with a hands-on, inside look at the world of technology. However, at the moment of truth on the playing field, the students control the robot and ultimately the outcome of the competition against other robots. FIRST represents a true team effort, and some of the bright young participants have decided to become engineers and scientists as a result of this exposure.



The 1998 FIRST playing field, showing team stations, and game balls in position for the start of a game. PNTA graphic by Kurt Giessler, Aleah Zolenski, Dave Cann and Russ Bozek.

Engineers, students and parents review a model playing field as they conceptualize appropriate design solutions for the 1998 competition. Photo courtesy Plymouth North Technical Alliance.

Team members of Lakewood High School's Center for Advanced Technologies watch to see if their ball handler's aim is on target. Photo by Marsha Ivins.

FIRST teams have demonstrated a remarkable ability to tap the intellectual and economic resources of government agencies, corporations, universities and communities for program mentors and funding. In fact, Corporate America provides most of the economic and professional support of the FIRST robotics program. Major corporations, the National Aeronautics and Space Administration (NASA), the National Science Foundation and military service academies provide backing for FIRST teams. These organizations obviously enjoy the stimulus and attention of sponsoring a worthwhile enterprise, while keeping an eye open for talented recruits.

Significant Growth

Growth of the robotics competition has been phenomenal. In the initial competition in 1992, twenty-eight teams competed, and in 1993 the number was twenty-five. Then, in 1994, forty-four teams were involved, and the number grew to fifty-nine in 1995, the first year the national championship was held at EPCOT Center. Ninety-three teams competed in 1996, and over one-hundred-fifty in 1997, the year the tournament held regional competitions in New Hampshire, New Jersey and Illinois. The regional system provides teams with the opportunity to practice with their robot against other teams before competing in the national championship at EPCOT.

In early 1998, regionals in Illinois, Michigan, New Hampshire, New Jersey and Texas helped prepare 199 teams for championship matches. In 1999, the expansion will continue; at least three-hundred teams are expected to compete in the tournament, with regionals being held in California, Connecticut, Florida, Illinois, Michigan, New Jersey, Pennsylvania and Texas.

The Competition

Each year, the rules for the competition are different. Details are secret until they are revealed at a January kick-off workshop in Manchester. This provides a high level of suspense and excitement as teams organize for each new competition. At the workshop, everyone is exposed to the new challenge for the first time, standard part kits are distributed, and ideas begin forming in everyone's minds.

After the kick-off, teams have six weeks in which they brainstorm, design, construct and test their robot. That is not much time to proceed from problem statement, to design specification and final product, and efficient organization is essential. One of the important skills learned by the students is the planning process, including critical path identification and time allocation. At the end of six weeks, the teams ship their robot to a competition center, where it remains until readied for the games.

All matches, including those in the regionals, have referees and time clocks. Often, the critical mass includes cheerleaders and pep bands. During the first day of competition, seeding rounds are conducted to determine the competitive placement of teams. On the second day, all teams compete in a double-elimination tournament, with three teams in

The Rolling Meadows High School/Wheeling High School composite team is interviewed by ESPN, while showing off their funky robot, "Wild Stang." Photo by Marsha Ivins.

the arena playing against each other and the clock. If a team loses twice, it is out of the competition, but the top teams go to the final rounds. During the finals, two teams compete against each other. This method of seeding is also used in the nationals.

Goals of the competition

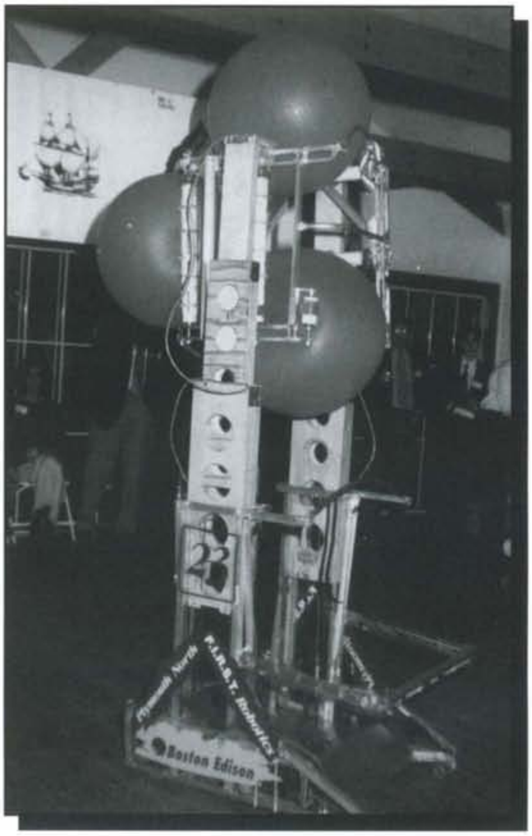
The primary goal of the competition is to develop an increased student awareness of science and technology.

Other goals are to:

- Create an environment that stresses the prestige of engineering and scientific careers.
- Stimulate engineers and scientists to remind them why they chose their career fields originally.
- Enhance the capabilities of engineers by fine-tuning their design, manufacturing and quality control skills.
- Develop goodwill within the community.

The 1998 games

The 1998 competition was typical of a FIRST tournament. Rules for the 1999 competition will be entirely different, but this description of last year's games demonstrates how complex the problem can be, given the limited amount of time for preparation.



The Plymouth North High School team's robot was designed to handle multiple balls, thus reducing the cycling time needed to score the most points. Here it is extended about half way. Photo by Paula Partridge.

The 1998 rules called for a robot that could collect, lift and transport 24 inch rubber sport balls. The robots performed on a hexagon-shaped playing field with an eight-foot tall, hexagon shaped central goal, and three sets of parallel steel rails radiating outward and upward from the central goal. The rails were divided into three zones for scoring purposes. The stations for student team members were just outside the playing field. Two robot drivers and a ball handler were allowed on each team. The ball handler could pick up balls, throw them into the arena, or hand them to the robot.

At the start of each competition, each of the three teams, red, white and blue, had nine balls corresponding to their team color. Three of the balls were already in place in one-point, two-point, and three-point scoring positions on the rails. Three more were placed around the playing field. A team member had the other three balls in the ball handler station.

The object of the game was to have the robot place as many team balls as possible in the central goal, and on the rail scoring zones. The farthest (and highest) zone from the center was worth the most points. Scoring was tallied at the end of each two-minute match, and points were awarded based on the location of balls on the scoring rails.

- Three points - balls placed in the outer third.
- Two points - balls placed in the middle third.
- One point - balls placed in the inner third.

Balls placed in the central goal did not count as points, but doubled the total accumulated on the scoring rails. For instance, if a team had one ball in the two-point scoring rail position, and two balls in the central goal, their score would be eight points, tallied as follows: Two points for the scoring rail goal, times two for one ball in the doubler, times two again for the second ball in the doubler (2 x 2 = 4, x 2 = 8). If a team had two balls in the central goal and zero balls on the scoring rails, their score was zero, since balls in the central goal did not count for scoring purposes (0 x 2 = 0, x 2 = 0).

Building a team

Other than having high school students as robot drivers and on-field ball handlers, there are no restrictions on who can be on a team. The FIRST project is more than the task of designing and building a robot from a standard set of raw materials. In fact, the effort required to form a team and compete mirrors the product development cycles common to research and manufacturing firms throughout the industrialized world. The talent requirements are also a close match.

Team members create competitive strategy, ensure rules compliance, document activities, and control the flow of work. They are responsible for logistics, and inventory control. Other responsibilities include practice field construction, driver selection and training, and manning the pit crew. The program rewards organizational acumen, decision making ability, and risk recognition and management, skills that are valued in industry. Companies need marketing services, design support and communication systems in order to function effectively, and so do robotics teams. Financing is simplified if the team can document its impact on the local community, so arranging press coverage for the team is also essential. Typically, a FIRST team will include some combination of the following categories of people.

The Plymouth North High School team celebrates winning the 1998 Chairman's Award. Photo by Marsha Ivins.

High School Students and Teachers

All students have different talents and enjoy different activities, and the FIRST project provides a forum for these diverse talents. Participating students need not be interested in engineering careers. A student who likes writing can be assigned as the team's publicist to handle press relations; a student strong in math may calculate the required geometry for the robot; a student who enjoys computers can develop a Web page for the team, and a student interested in art can design the team's logo and robot aesthetics. Interest and motivation are the keys, and there is room on the team for students in every field. Many become interested in engineering as a result of their participation. The best team members are self-starters and creative problem-solvers who make effective use of technological resources to gain advantage over their competitors.

Faculty involvement is critical for the project. Faculty members serve as mentors and supervisors, as well as coaches for specific components of the project. Their involvement is vital in generating enthusiasm and support for the project from within the school system.

Industry Engineers and Technicians

This group of mentors is crucial to success, and its nucleus should include at least an electrician, a machinist, and two engineers, one of whom should have experience in product development. Included in this key category are employees from technical research centers operated by the U.S. government.

University Faculty and Students

A number of FIRST teams have included university participants. There are many ways for university students and faculty to participate in FIRST. For instance, some universities have used FIRST team participation as an undergraduate capstone design project or professional society activity, and others have used FIRST in their graduate curriculum.

Others

Interested parents, community members, retired teachers or engineers, and non-engineering industry representatives are important. Typically, this group assists in coordinating parts of the project beyond the design and construction of the robot.

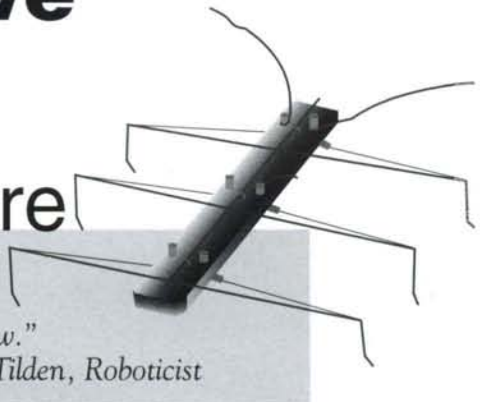
The combination of interested parties varies from team to team, but the typical high school team would include mentors from government, industry, schools and universities. For example, a coalition team could include mentors from multiple companies, and university or high school faculties competing as a single team. In another example, one company may elect to sponsor a team that represents several high schools in a system, or a group of companies may join to collectively sponsor and provide staff for a single team.

Having high-level industry team members with executive backgrounds, or experience in public affairs, is a smart way to help secure resources, exposure and recognition. These elements are critical to the project's success, particularly in the area of fundraising.

(Continued on page 57)

Building an Inexpensive Insectoid Robot

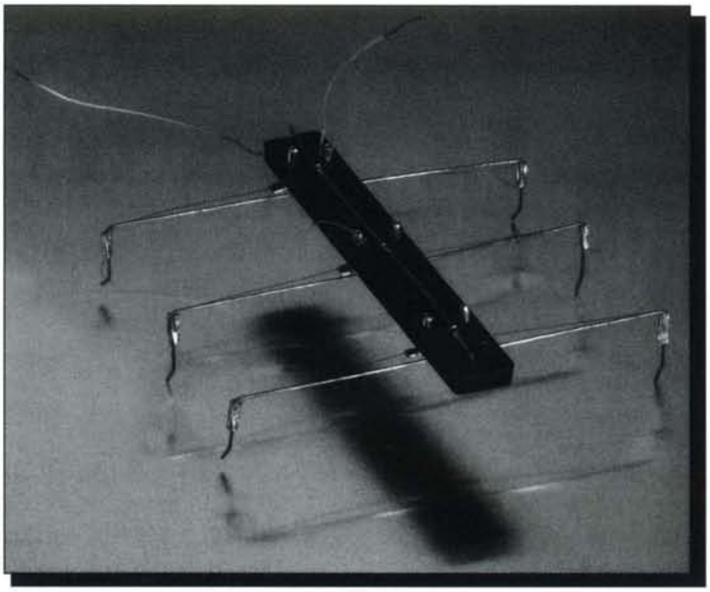
Propulsion Using Nitinol Wire



When it was first announced that a "robot muscle" had been invented and that it was usable, strong, and lightweight, the resounding cry was "boy, aren't we gonna see some cool robots now."

—*Mark Tilden, Roboticist*

by James M. Conrad, PhD, Ericsson, Inc, and Wayne Brown, Dynalloy, Inc



Stiquito

Introduction

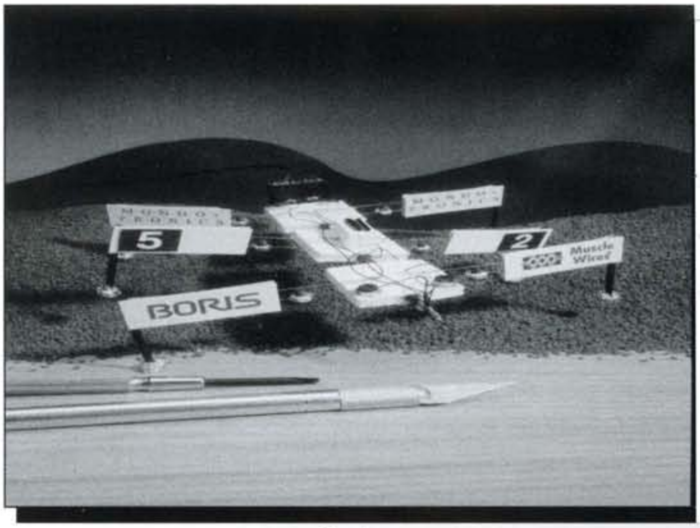
Designing and building a robot is an exciting and challenging project, and you have several choices to make early in the process. You need to decide if it will be expensive or inexpensive, big or small, smart or not? Will it walk or will it roll, and will it be required to traverse flat or rough surfaces? Sometimes the answers to these questions are influenced by your financial resources. If your robot must be inexpensive, or you are just starting out in robotics and want to keep it simple, a practical solution for you is an insectoid robot. This article is about insectoid robots, which are small, thin, insect-like walkers that use artificial muscles for propulsion. They are educational and inexpensive to build.

The enabling element in these robots is nitinol, an alloy actuator wire that expands and contracts, roughly emulating the operation of a muscle. The application of heat causes a crystalline structure change in the wire. Thus, nitinol contracts when heated, and returns to its original size and shape when cooled. An improved derivative of nitinol is Flexinol[1], an alloy actuator wire with enhanced movement and stroke endurance characteristics, and life cycle advantages over basic nitinol. Flexinol has spawned a family of small, inexpensive walking robots including Stiquito and Boris.

Nitinol Actuator Wire

Nitinol is shape-memory alloy actuator wire made of nickel and titanium. This material, when produced as small diameter wires, contracts like muscles when electrically heated. The ability to flex, or shorten, is characteristic of nitinol alloys which dynamically change their internal structure at certain temperatures. A counterforce, or bias, is required to return the nitinol to its original length or shape.

The nitinol wire translates the heat induced by an electrical current into mechanical motion. The idea of elevating temperature electrically is used in the light bulb. Instead of producing light, nitinol wire contracts by several percent of



Boris

[1]Flexinol is a registered trademark

its length when heated, and can then be easily stretched out as it cools. Like the filament in a light bulb, nitinol reacts quickly to heating and cooling. This contraction of nitinol wires when heated is larger by a hundred-fold and opposite to ordinary thermal expansion. It exerts a tremendous contractive force, given its small size. The underlying technology that causes the effect is discussed below and depicted in Figure 1. The main point is that the contraction is silent, smooth and powerful, and occurs through an internal solid state restructuring of the material.

The function of the nitinol wire is based on the shape-memory phenomenon that occurs in certain alloys in the nickel-titanium family. When nickel and titanium atoms are present in about a 1/1 ratio, the material at normal temperatures is in a relaxed or expanded crystalline state referred to as the 'martensitic state.' When the wire is heated above a certain temperature the material becomes rigid and contracts as it assumes what is referred to as the 'austenitic state' ① in Figure 1. This temperature, A_t, is the austenitic transformation temperature. In this state nitinol exhibits high strength and is not easily deformed. As long as the temperature of the wire is kept slightly above A_t, the wire will remain contracted. When the heat is removed and the temperature falls below a certain temperature it returns to the 'martensitic state' crystal form. This temperature, M_t, is the martensitic transformation temperature. The low temperature martensitic crystal form of the alloy can easily undergo reversible deformation (i.e., can be stretched to its original cooled dimension), ② in Figure 1, under an opposing or 'bias force.'

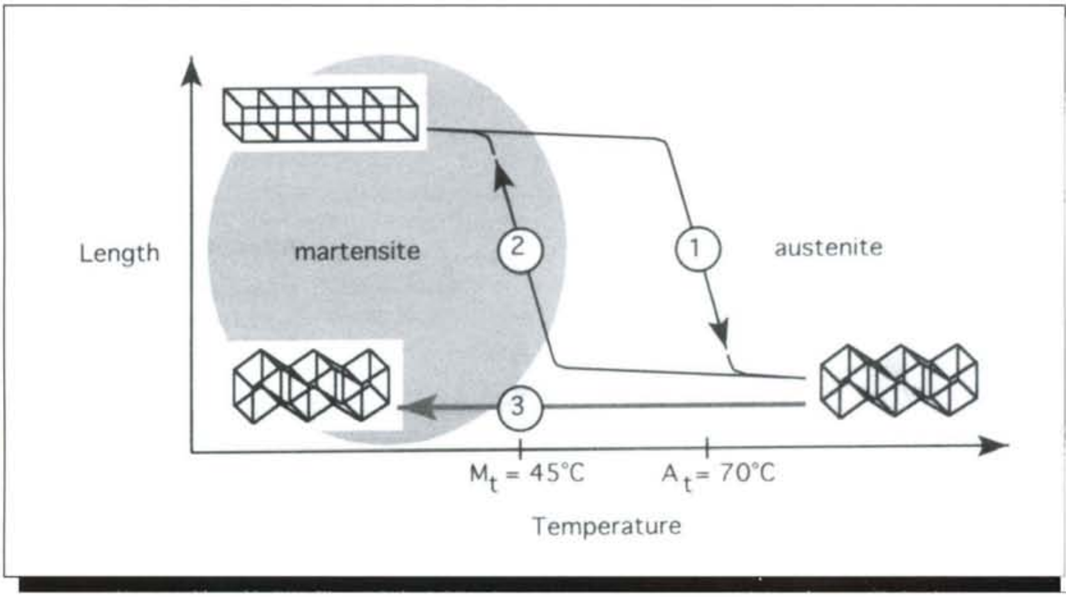


Figure 1. The Operating Cycle of nitinol:
①Heating ②Cooling with a bias force ③Cooling without a bias force.

The contraction of nitinol wire is measured as a percentage of the length of the wire. The stroke is determined, in part, by the level of bias force used to reset the wire, or to stretch it in its low temperature phase. If no bias force is applied as the temperature falls below M_t, then the wire will remain short as it returns to the martensitic state ③ in Figure 1. In most applications, the bias force is exerted constantly on the wire, and on each cycle as the wire cools, it is elongated by this bias force. If no force is exerted as the wire cools, very little deformation or stretch occurs during the cooling phase, and correspondingly very little contraction occurs upon reheating. Up to a point, the higher the load, the longer the stroke. The strength of the wire, its pulling force and the bias force needed to re-stretch the wire, are functions of the wire's cross sectional area. By the transformation process described in Figure 1, nitinol wire can change its length by as much as 10 percent.

Far more important to stroke is how the nitinol wire is physically attached and made to operate. Dynamics in applied stress and leverage also vary how much the actuated wires move. While normal bias springs which increase their force as the nitinol contracts induce only a 3-4% stroke, reverse bias forces which decrease as the nitinol contracts can readily allow the wire to shrink by up to 7%. The mechanics of the device in which it is used can convert this small stroke into movements over 100% of the wire's length and at the same time provide a reverse bias force. The stress or force exerted

	Approximate Stroke	0.004" Wire	0.006" Wire	0.008" Wire	0.010" Wire
Dead Weight Bias	4%	**150g**	**330g**	**590g**	**930g**
Leaf Spring Bias	7%	**150g**	**330g**	**590g**	**930g**
Simple Lever (6:1 ratio)	30%	**22g**	**47g**	**84g**	**133g**

Table 1: Stroke and Available Force of Flexinol

Wire Diameter Size	Resistance in Ohms per inch	Maximum Pull/Force	Approximate Current at Room Temperature	Contraction Time	Off Time 70°C Wire	Offtime 90°C Wire
0.004″	3	150g	180mA	1 sec.	0.8 sec.	0.4 sec.
0.006″	1.3	330g	400mA	1 sec.	2.0 sec.	1.2 sec.
0.008″	0.8	590g	610mA	1 sec.	3.5 sec.	2.2 sec.
0.010″	0.5	930g	1000mA	1 sec.	5.5 sec.	3.5 sec.

Table 2: Electrical Characteristics of Flexinol

by nitinol wires is sufficient to be leveraged into significant movement and still be quite strong. Some basic structures, their percent of movement, and the approximate available force they offer in different wire diameters are shown in Table 1.

Electrical Guidelines

If the more advanced derivative of nitinol, called Flexinol, is used within the guidelines presented in Table 2, tens of millions of cycles can be obtained from the wire. If higher stresses or strains are imposed upon less capable forms of nitinol, then the memory strain is likely to slowly decrease and good motion may be obtained for only hundreds or a few thousands of cycles. The permanent deformation that occurs in the wire during cycling depends heavily upon the stress imposed and the temperature under which the actuator wire is operating. Flexinol has been specially processed to minimize this straining, but if the stress is too great or the temperature too high, some permanent strain will occur even in Flexinol. Since temperature is directly related to current density passing through the wire, care should be taken not to overheat the actuator wire. Table 2 presents rough guidelines as to how much current and force to expect with various wire sizes.

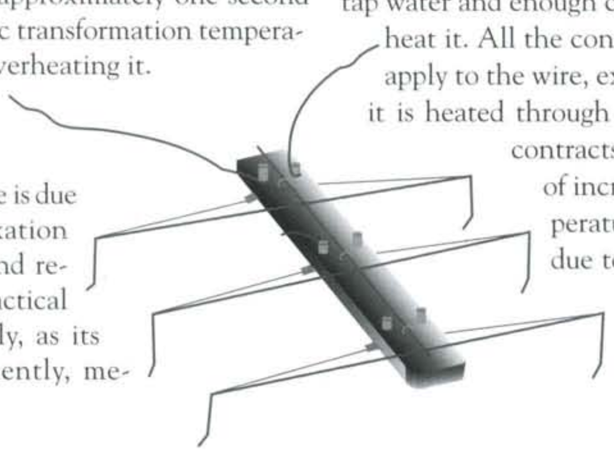
The contraction time, in Table 2, is directly related to current input. The figures used here are only approximate, since room temperatures, air currents, and heat sinking of specific devices vary. Currents that take approximately one second to heat the wire past the austenitic transformation temperature, A_f, can be left on without overheating it.

Cycle Time

The contraction of the nitinol wire is due solely to heating, and the relaxation solely to cooling. Contraction and relaxation of the wire occur (for practical purposes) almost instantaneously, as its temperature changes. Consequently, mechanical cycle speed is dependent on, and directly related to temperature change. Applying high electrical currents for short periods of time can quickly heat the wire. It can be heated so fast that the limiting factor is not the rate at which heating can occur, but rather the stress created by rapid movement. If a loaded wire is made to contract too fast, the inertia of the load can overstress the wire. To perform high-speed contractions, inertia must be kept low, and the current should be applied in short, high-energy bursts. Naturally, a heavy current that will heat the wire rapidly from room temperature to over 100° C in one millisecond will overheat the wire if applied for an additional millisecond of time.

While each device has quite different heat sinking and heating requirements, a simple visual observation can detect overheating. Measuring the actual internal temperature of the wire across short time periods is difficult to do. However, one can tell if the actuator wire is overheated simply by observing if the wire immediately begins to cool and relax when the current is shut off. If it does not promptly begin to relax and elongate under a small load when the power is cut, then the wire has been needlessly overheated and may have been damaged.

Nitinol wire has high resistance compared to copper and other conductive materials, but it is still conductive enough to carry current easily. In fact, one can immerse the wire in regular tap water and enough current will readily flow through it to heat it. All the conventional rules for electrical heating apply to the wire, except that its resistance goes down as it is heated through its transformation temperature and contracts. This is contrary to the general rule of increased resistance with increased temperature. Part of this drop in resistance is due to the shortened wire, and part is because the wire gets thicker as it shortens, roughly maintaining its same three-dimensional volume.



This characteristic occurs whether using alternating current, direct current, or pulse width modulated current.

Relaxation time is the same as cooling time, and this time can be greatly influenced by heat sinking and other design features. There are several ways to speed up the cooling cycle, but the simplest way is to use smaller diameter wire. The smaller the diameter, the more surface area-to-mass the wire has, and the faster it will cool. Also, additional wire, even multiple strands in parallel, can be used to exert whatever force is needed, while increasing the exposed surface area and thus the cooling speed. Finally, cooling time can be improved by using higher temperature wire. This wire contracts and relaxes at higher temperatures. Accordingly, the temperature differential between ambient or room temperature and the wire temperature is greater, and correspondingly the wire will drop below the transition temperature faster in response to the faster rate of heat loss.

Other methods of improved cooling are to use forced air, heat sinks, increased stress (this raises the transition temperature and effectively makes the alloy into a higher transition temperature wire), and liquid coolants.

Miscellaneous

Cutting. Nitinol wire is a very hard, anti-corrosive material. It is so hard that tools designed for cutting copper and soft electrical conductors will be damaged if used on nitinol. If you plan to do much work with nitinol wires, you should invest in a high quality tool designed to cut stainless steel wires.

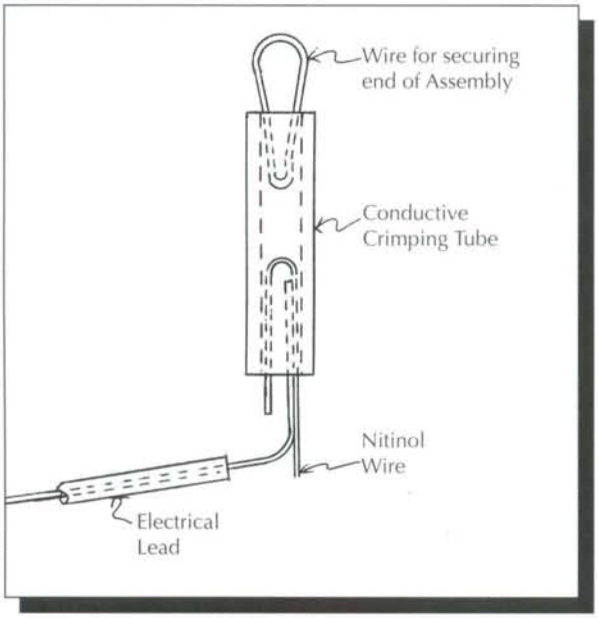


Figure 2
Typical crimped connection

Attaching. Nitinol wire can be attached in several ways to make a physical, as well as electrical connection. It can be attached with screws, wedged onto a PC board, glued into a channel with conductive epoxies, and even tied with a knot. The simplest and best way is usually by crimping or splicing. With crimping machines, electrical wires and hooks or other physical attachments can be joined at the same time. Nitinol wire is a very strong material and is not damaged by the crimping process. For a typical crimped electrical connection see Figure 2.

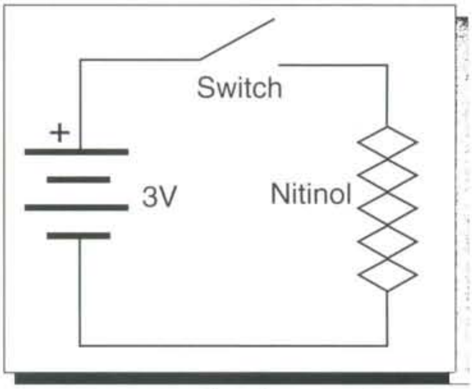


Figure 3: The Schematic for all Experiments

Nitinol wires tend to maintain the same volume, so when they contract along their length, they simultaneously grow in diameter. This means the wire expands inside the crimp. Since the swelling never exceeds the elastic limits of the crimp, it holds more firmly as the stress increases due to pulling. This can be a disadvantage if glue or solder is used, since the material tends to work itself loose in those cases.

Connecting Materials. When nitinol is heated, its temperature often climbs to over 100° C, and the wires apply strong pressure over a small area of the device to which they are attached. It is a good idea to use temperature-resistant materials at connection points. Such materials, if used in direct contact with the wire, will also need to be non-conductive so an electrical path is not created around the nitinol wire. Silicone rubber, commercial products used to make flexible circuit boards, ceramics, and glass are good examples of materials that can be used.

Reverse Bias. Nitinol wire contracts about 4.5% when lifting a weight or working against a constant force. This load is also the bias force, which will return the wire to its original length when the wire cools. The length of the stroke can be improved by introducing mechanisms that have a reverse bias force. The bias force is the force that elongates the wire in its rubber-like martensitic phase, returning it to its original shape. A reverse bias force is one that gets weaker as the stroke gets longer (i.e. does not remain constant as in the weight lifting or constant force experiment, which follows). This can be done with leaf springs or with designs that give the nitinol wire a better mechanical advantage over the bias spring, or force, as the stroke progresses.

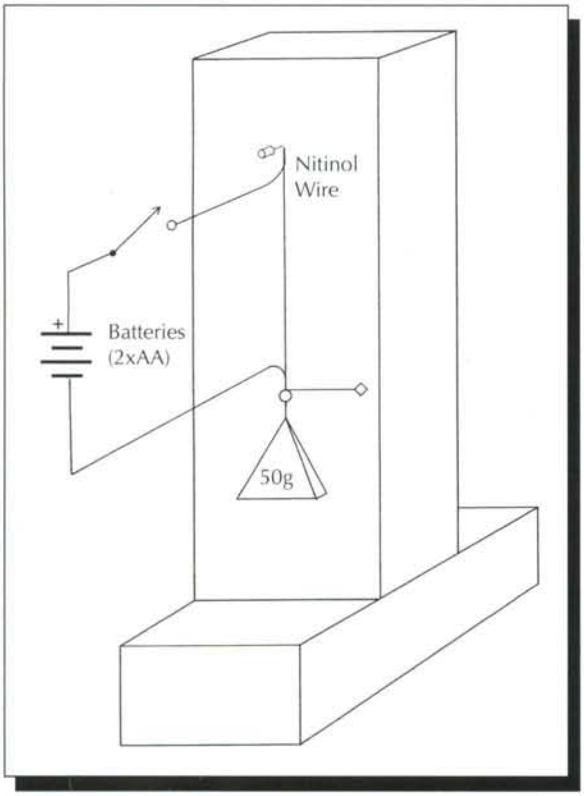


Figure 4: Raising a Dead Weight with Nitinol

Dead Weight Lift — Nitinol Extended
Switch Open — ◇ Baseline Mark

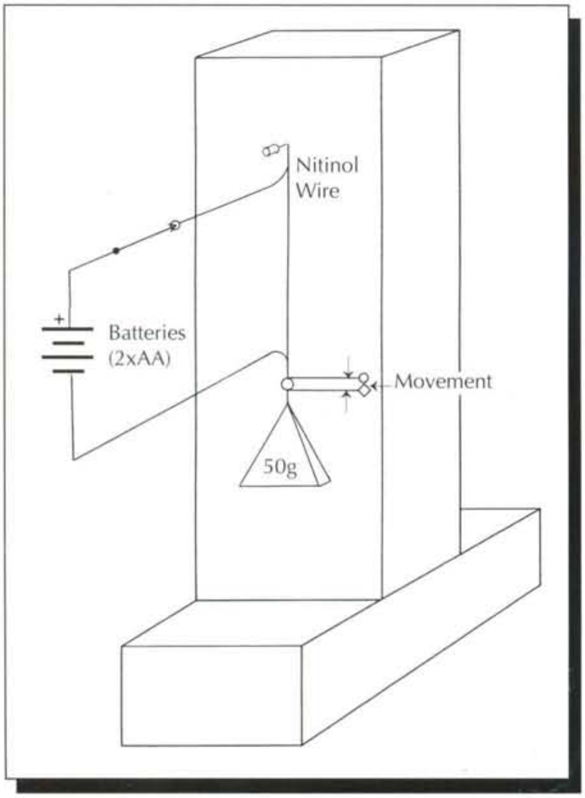


Figure 4a

Dead Weight Lift — Nitinol Contracted
Switch Closed — ○ New Data Mark
◇ Baseline Mark

Experimenting with Nitinol

An important part of building your robot includes understanding how nitinol works, and since the best way to learn is by doing, we have devised three experiments to help you learn about nitinol actuator wires. The experiments consist of three different mechanical setups, yet all use the same electrical schematic shown in Figure 3. Note: Flexinol is specified for use in all three of the following experiments.

Materials List For Experiments

You will need the following materials to perform these experiments. Keep in mind that each experiment uses a subset of these materials.

- One 4 inch (about 100 mm) length of 0.004 inch diameter Flexinol wire, pre-crimped, with insulated wires attached.
- Two AA batteries
- One 2 AA cell battery holder (available at RadioShack)
- Pushpins
- One 2 x 4 x 12 inch wooden board for holding the experiments
- 20 US pennies ((or other 50 gram (dead weight experiment) and 7.5 gram (lever experiment) mass))
- One small plastic bag to hold the coins
- Wire-wrap wire, as needed
- One 4 inch (about 100 mm) length of 0.032 -in. music wire (spring wire), like K&S Engineering No. 501, found in hobby stores
- One 3 by 1/2 inch piece of thin wood, cardboard, plastic, or metal to serve as a lever
- One low voltage momentary switch

The Dead Weight Experiment

This first experiment examines lifting a dead weight, 50 grams of coins, and measuring the distance the nitinol wire contracts. Flexinol 0.004 inch diameter wire, which has 150 grams of available force, is specified. Since one-third of this force is needed to recover the length of the nitinol, we use 50 grams of mass. This experiment uses all of the materials except the music wire and lever. To build the setup for this experiment, see Figure 4.

1. Place all 20 coins in the bag and tie the bag to one crimp grommet of the nitinol wire.
2. Using a pushpin, anchor the other end of the wire near the top of the 2 x 4 inch board. Allow the bag of coins to hang by the wire. Do not let it touch your tabletop.
3. With a pencil, mark the location of the lower grommet. Later, you will mark the location of this grommet when the nitinol is heated.

4. Insert your two AA batteries into the battery holder, and connect one of the battery wires to one of the insulated wires attached to the nitinol.
5. Connect the remaining two wires to the momentary switch.
6. Press the switch briefly, for no more than one second, and observe the contracted length of the wire. Mark the lower grommet hole while the nitinol is heated. Allow the wire to cool fully before you heat it again.

The result of this experiment is that the wire can lift a lot of mass, but only a short distance. The length the Flexinol should contract is 2 to 4% or only 2 to 4 mm.

The Lever Experiment

The next experiment examines lifting a weight using a mechanical lever. You will measure the distance the lever moves. Flexinol 0.004 inch diameter wire, which has 22 grams of available force for a 6:1 lever, is specified. Since one-third of this force is needed to recover the length of the wire, we use 7.5 grams of mass, which is three US pennies. This experiment uses all of the materials except the music wire and most of the coins. To build the setup for this next experiment, see Figure 5.

1. Make your lever by identifying the pivot point and making a hole big enough for a pushpin. Measure 10 mm from the pivot and make another hole for anchoring the nitinol wire. Measure 50 mm from this second hole and make a third hole for attaching the weight. If you use wood, you may be able to use pushpins instead of making a hole for the nitinol and weight.
2. Place three pennies in the bag and tie the bag to the last hole with wire-wrap wire.
3. Attach one crimp grommet of the nitinol wire to the second hole with wire-wrap wire.
4. Attach the lever to the 2 x 4 inch board, pushing the pin through the first hole into the board.
5. Using a pushpin, anchor the other end of the nitinol wire near the top of the 2 x 4 inch board. Position the wire so that the lever is 30 degrees below horizontal (at the 4 o'clock position).
6. With a pencil, mark the location of the third lever hole. Later, you will mark the location of this holes when the nitinol is heated.
7. Insert your two AA batteries into the battery holder, and connect one of the battery wires to one of the insulated wires attached to the nitinol.
8. Connect the remaining two wires to the momentary switch.

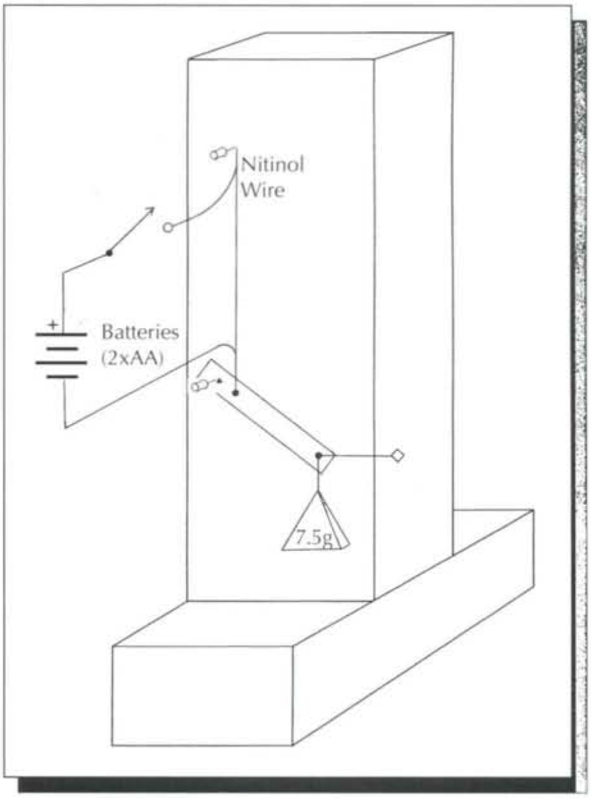


Figure 5: Raising a Simple Lever with Flexinol

Simple Lever — Nitinol Extended
Switch Open — ◇ Baseline Mark

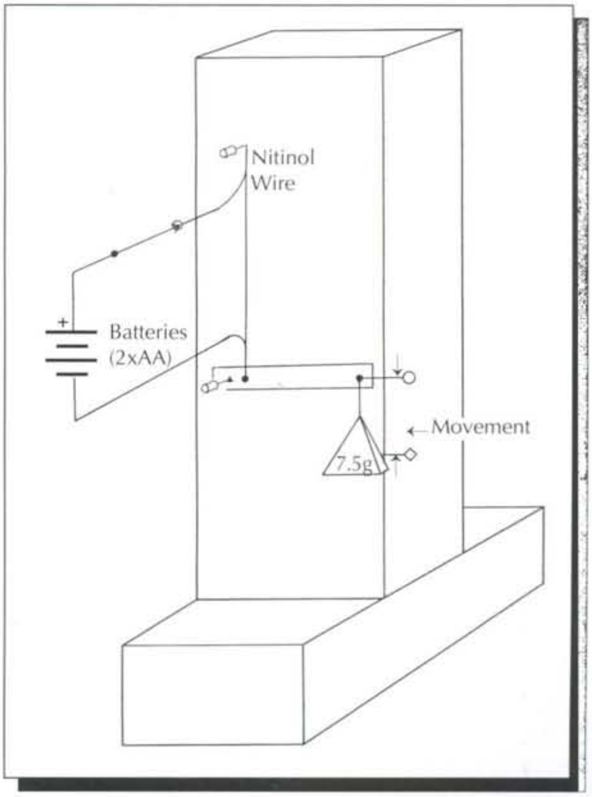


Figure 5a

Simple Lever — Nitinol Contracted
Switch Closed — O New Data Mark
◇ Baseline Mark

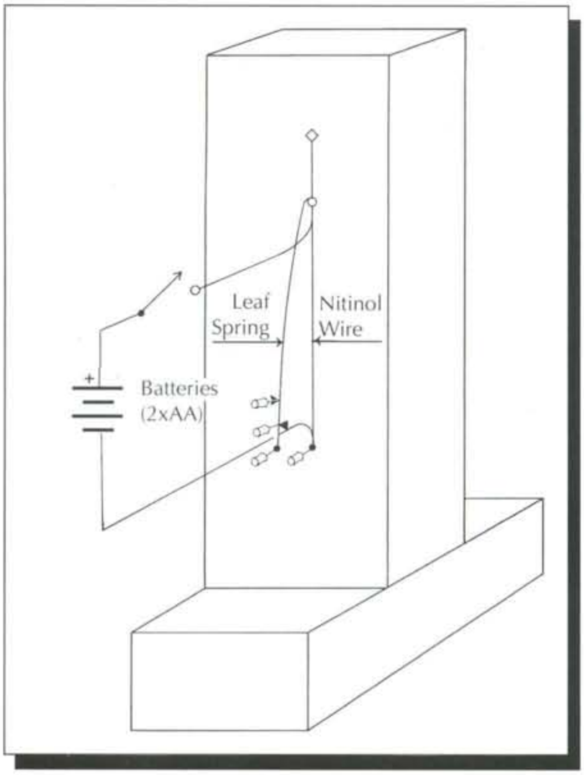


Figure 6: Using Flexinol and Music Wire to Make a Leaf Spring Bias "Leg"

Leaf Spring Switch Open

Nitinol Extended

◇ Baseline Mark

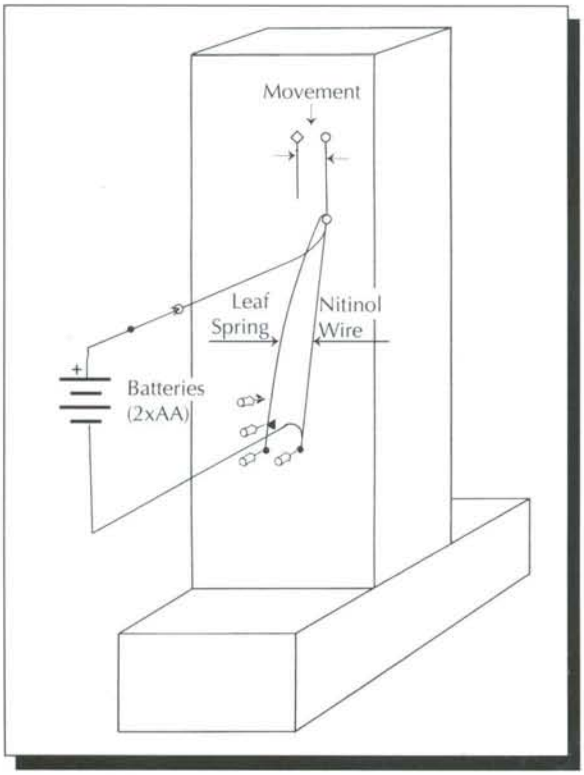


Figure 6a

Leaf Spring Switch Closed

Nitinol Contracted

○ New Data Mark

◇ Baseline Mark

9. Press the switch briefly, for no more than one second, and observe the amount of length that the wire contracts and the lever rises. Mark the third lever hole while the nitinol is heated. Allow the wire to cool fully before you heat it again.

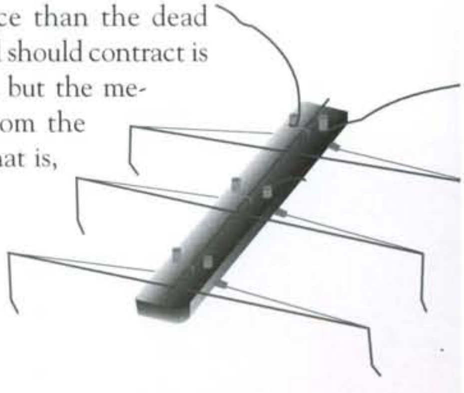
The result of this experiment is that the wire can only lift a lighter mass, but a greater distance than the dead weight. The length the Flexinol should contract is 2 to 4%, or only 2 to 4 mm, but the mechanical motion obtained from the lever will be 6 times that, or 12 to 24 mm.

The Leaf Spring Experiment

This experiment examines bending a spring wire and allowing the spring to pull the nitinol back into position. You will measure the distance the spring moves. Flexinol 0.004 inch diameter wire, which has 150 grams of available force, is specified. This experiment uses all of the materials except the bag, lever, and coins. To build the setup for the following experiment, see Figure 6.

1. Bend both ends of the music wire into loops using needle nose pliers.
2. Using three pushpins, anchor one end of the music wire to the 2 x 4 inch board. Put one of the pins in the loop, and then position the two to anchor the wire to the board.
3. Hook one end of the nitinol wire onto the music wire loop.
4. Using a pushpin, anchor the other end of the nitinol wire to the 2 x 4 inch board. Position the pin so that the music wire is slightly bent and the nitinol is held taught.
5. With a pencil, mark the location of the nitinol and music wire loophole. Later, you will mark the location of this hole when the nitinol is heated.
6. Insert your two AA batteries into the battery holder, and connect one of the battery wires to one of the insulated wires attached to the nitinol.
7. Connect the remaining two wires to the momentary switch.
8. Press the switch briefly, for no more than one second, and observe the amount of length that the wire contracts and the spring wire moves. Mark the music wire loophole while the nitinol is heated. Allow the wire to cool fully before you heat it again.

The result of this experiment is that the nitinol wire can move the music wire a greater distance than the dead weight. The length the nitinol should contract is 2 to 4%, or only 2 to 4 mm, but the mechanical motion obtained from the music wire will be 4 to 7%, that is, 4 to 7 mm.



Concluding Thoughts

The above experiments are just a few that can be performed which demonstrate the unique characteristics of nitinol wire. A fertile imagination can conceive of many more. These experiments can be performed at home or in the classroom. They are convincing evidence that nitinol/Flexinol is an effective tool for robotic actuation. The insights gained through this hands-on experience can contribute to the knowledge base of all roboticists, particularly those who may be just beginning. Much more complex and versatile actions and reactions can be achieved using pulleys, rockers, opposing wires, various heating and cooling media, etc., to accomplish tasks. All that is required is a small investment, and the return can be truly significant. If you can generate enough interest to make them a shared project, the accumulated knowledge can lead to bigger and better bots. Additional information on nitinol-based robots will be published in future issues of *Robot Science & Technology*.

RS&T

***James Conrad** is a senior staff engineer at Ericsson, Inc., in Research Triangle Park, NC. He received his bachelor's degree in computer science from the University of Illinois, and his master's and doctorate degrees in computer engineering from North Carolina State University. Dr. Conrad is the author of numerous journal articles and conference papers, and has written books on robotics, parallel processing, artificial intelligence and engineering education.*

***Wayne Brown** is the founder and president of Dynalloy, Inc., the manufacturer of Flexinol actuator wires. He received his bachelor's degree from Brigham Young University. Mr. Brown has been involved in the computer and robotics fields for over 27 years. He has developed numerous products of his own, and assisted in the design of several hundred others. During the last ten years, he has concentrated on improving the properties of actuator wires being produced by his company for commercial applications.*

Reference

Technical Characteristics of Flexinol Actuator Wires, Dynalloy, Inc., Costa Mesa, CA

Information Sources

Additional information on nitinol, and nitinol-based robots can be found at the following web sites:

Dynalloy: www.dynalloy.com

Mondo-Tronics: www.robotstore.com

Stiquito: www.stiquito.com or computer.org/books/stiquito

References

For additional information about Nitinol:

Stiquito™ Advanced Experiments With a Simple and Inexpensive Robot
by James M. Conrad & Jonathan W. Mills
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Tel 415.491.4600, Fax 415.491.4696
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www.RobotStore.com
ISBN 1-879896-16-8, $59.95 + S/H

The centerfold of the November issue of RS&T, the Sony entertainment-type robot, is a prime example of how cool a robot can look with a little extra effort! In this continuation of our fabrication series, we will acquaint you with a technique you can use to clothe your robot in a sleek outer garment. Just think, no more dangling wires, sharp edges, or disconcerting metallic glare to distract you from the graceful movements of your robot as it goes about its assigned tasks! In keeping with the basic philosophy of this series, vacuforming is something you can do in your own home. *You can do this in your kitchen.*


Photo courtesy of Sony Corporation

Vacuforming on a Shoestring

Your Robot is Ugly - But It Doesn't Have To Be

by Flint Mitchell

Vacuum forming is a quick and easy way to make a variety of objects, from remote control car bodies to model kits, shark-proof armor, and robot parts. This article will focus on male mold vacuforming, and a brief explanation of the process will probably help.

The male mold master is the object or shape that is to be replicated in plastic, to sheathe part of your robot. The basic idea is simple: First, a plastic sheet is heated until it is soft and then placed over the mold master. A vacuum is created, and the air between the mold and the plastic is removed, drawing the soft plastic tight to the mold master. Generally, it helps to have someone work with you when you do this; one person handles the holding frame with the softened plastic and another turns on the vacuum, normally a vacuum cleaner. If you try this alone, the plastic can cool slightly on the mold while you are going from the mold to the vacuum cleaner. One way around this is to put a switch on the vacuform box itself, so that the vacuum cleaner is switched on as soon as the plastic is set on top of the box.

You may already have all the materials needed for vacuforming around the house, except the plastic sheeting. Once you have your system set up, the time from conception to execution can be a matter of an hour or less. If you're lucky enough to find a male mold master that is the right size and with a flat bottom, you can be producing parts in minutes. When I was new at this, I had a couple of false starts (mostly due to edge seal problems), before I produced my first usable part. However, to tell the truth, the simplicity of the process is quite amazing. Starting from scratch, in a few short hours you could be making some truly cool robot parts.

Getting started in Vacuforming

Basic Equipment

A heat source. An oven is the ideal heat source in which to heat the plastic. First, measure the width of your oven, since you don't want to build a holding frame for the plastic that will not fit in the oven. Most ovens are wide enough to accommodate all but the largest of projects. If you have both an electric and a gas oven, use the electric oven, since electric ovens tend to provide a more even heat source. A gas oven will work, but it will take longer for the plastic to get to the right softness. The information presented in this article is based on the use of an electric oven.

If your electric oven has a light that turns on when the heating element is on, pay attention to it. When the element is on, the plastic heats and softens rapidly. You could have a piece of plastic that is not quite ready one second, and burning on the bottom of the oven the next.

If you have an oven without a window in the door, you'll have to open the oven periodically to check the plastic. Do this quickly, since heat will escape. This will slow the softening process. A good heat source for small projects, three inches by three inches or less, is a heat gun. When applying the heat this way, move the gun around to heat the plastic evenly. When it has softened enough, put the frame on your vacuform box, and turn on the vacuum.

A vacuum source. A powerful vacuum cleaner works best for this. A 2.75 horsepower Sears Shop-Vac works very well. A hose size of 1-1/4 inch works best since larger hoses tend to achieve lower levels of vacuum.

A vacuform box. Essentially, a vacuform box has:

- A hole in one side to accommodate the vacuum source,
- a board on top with evenly spaced holes (pegboard works well), and
- a rim of plywood or weather-stripping that forms a well in which the male mold master sits (the peg board is the floor of the well). This raised rim is the sealing surface around which the holding frame for the plastic, discussed below, is placed. The well it creates must be deep enough to accommodate the male mold master.

On one side of the box, cut a hole for the vacuum cleaner hose. A standard hole-cutting saw can be used for the hose entry point, but whatever you use, the hose has to fit snugly. The box can be constructed as you see fit, but it must be airtight. A duct tape and Masonite box will work as well as a more elaborate design, and the box shown in Photo 1 is typical. It doesn't have to be fancy, and vacuform boxes have even been made from square cake pans. The larger the box, the sturdier it must be built to withstand the pressure.

An edge seal is required so that air cannot leak into the box and destroy the vacuum. To make the seal, simply cut some plywood pieces to fit, and hot glue them to the box. If the

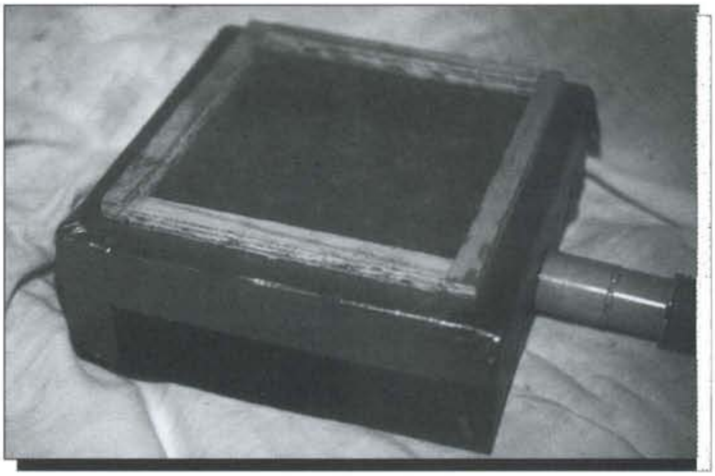


Photo 1: The vacuforming box. Note the wood pieces on the top, which act as a seal around the edges. Note also the vacuum cleaner hose in the lower right. Note also the judicious use of the handyman's secret weapon: duct tape!

well can be shallow, weather stripping will also work. In creating the rim, the sealing surface, keep in mind the thickness of the seal will be the same as the thickness of the lower half of the holding frame for the plastic. Be sure that the upper edge of the lower holding frame is even with the sealing surface. At this point in your project, a piece of plastic placed on the lower holding frame should sit evenly on the frame and the seal, with neither the seal nor the frame being higher (see Figure 1).

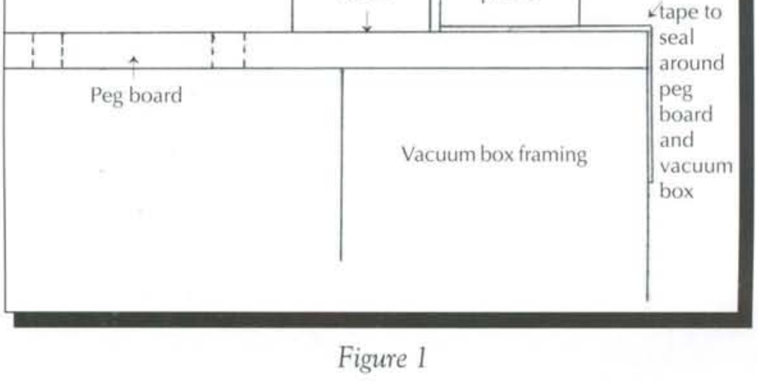


Figure 1

On sizing your vacuform box, it is recommended that it be just large enough to accommodate your project. For example, constructing a two foot wide box, when making a two inch part, will waste a lot of plastic. Some space is needed around the part to insure the vacuum pulls the plastic down tight, but don't overdo it. A good rule of thumb would be to measure the part and add an inch or more on each side. When making a box of any appreciable size

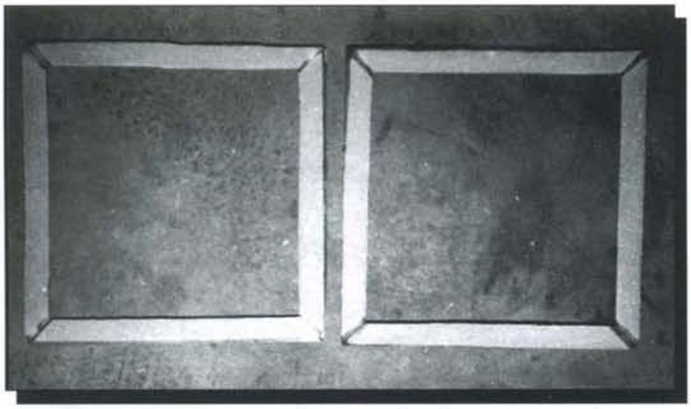


Photo 2: The two inside halves of the plastic clamping frame. Note the sandpaper on each surface.

(six inch square or larger), provide support for the pegboard. This will prevent its collapse due to the external pressure of the atmosphere when the vacuum is applied.

A holding frame for the plastic. This can be made of wood, if you wish, since it won't be in the oven very long. Wood frames have been used for years with no scorching. The frame must be able to fit *comfortably* over the sealing edge on the vacuforming box.

How the holding frame for the plastic is assembled is optional. Butt joints will work just as well as miter joints. Essentially, the apparatus is two square frames that hold the plastic between them. Photo 2 is an example of a holding frame. It's no marvel of engineering, but it has served admirably for over a decade. You need a method of holding the plastic securely in the frame. Spring clamps are one acceptable method. Use contact cement to glue pieces of coarse sandpaper where the frame will grasp the plastic. The sandpaper insures a good grip.

Be sure to have some method of holding the frame, perhaps a pair of handles. If using spring clamps, they can be used as handles as well (see Photo 3). Keep your hands away from the plastic, when it's heated it will tear easily.

A metal standoff. A standoff is needed to keep the plastic from making contact with the oven and burning! A standoff about four inches tall, and slightly smaller than the frame, so that the frame sits easily on top, works well (see Photo 4).

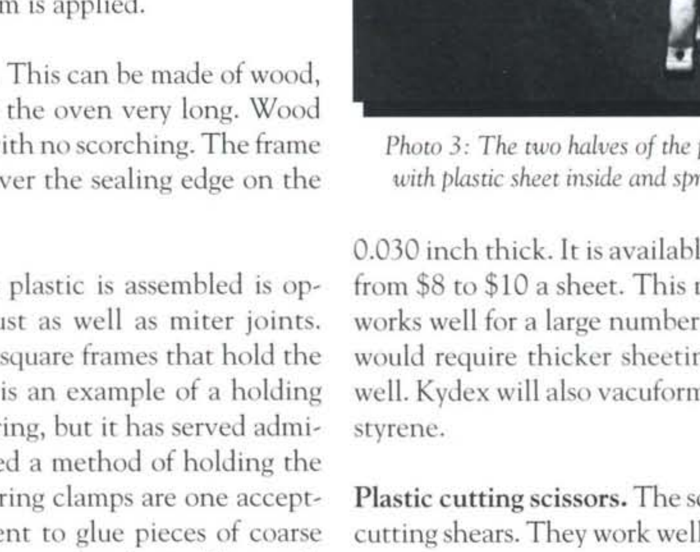


Photo 4: The plastic clamping frame in the oven. Note the metal standoff, which is supporting the frame.

The plastic. For vacuforming, generally use sheet styrene,

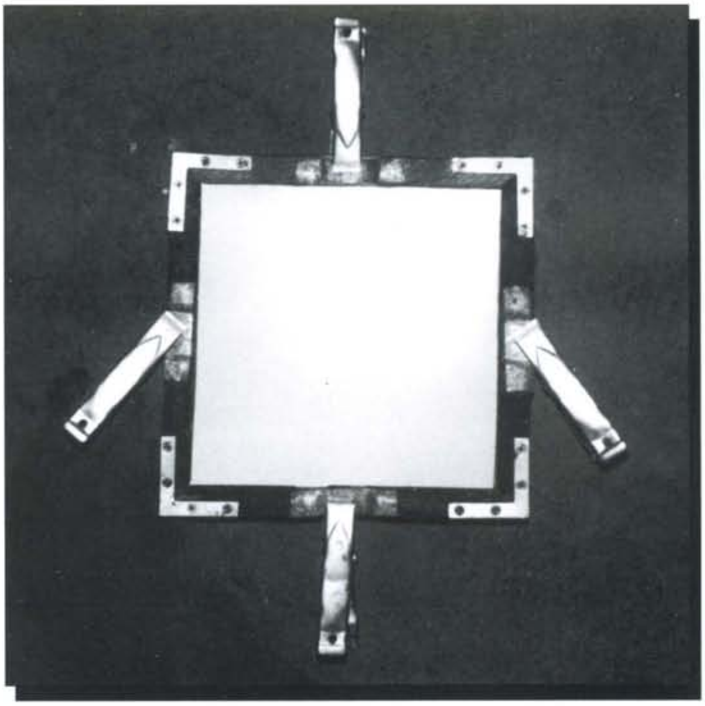


Photo 3: The two halves of the plastic holding frame, complete with plastic sheet inside and spring clamps holding it together.

0.030 inch thick. It is available in 4 x 8 foot sheets, and costs from $8 to $10 a sheet. This material is recommend since it works well for a large number of projects. Only larger pieces would require thicker sheeting. Clear vinyl also vacuforms well. Kydex will also vacuform, but it is more expensive than styrene.

Plastic cutting scissors. The scissors I use are known as penny cutting shears. They work well for styrene, and never get dull.

Hand protection. Hand protection is essential when handling the hot holding frame, its clamping devices or the standoff. To avoid burns when handling these items, always wear insulated gloves. **Do not under any circumstance use latex, plastic or rubber gloves! Insulated gloves are recommended over oven mitts and potholders because they allow greater manual dexterity while providing the protection you need.**

Limitations of Vacuforming

Any shape with an undercut cannot be vacuformed in one piece. An undercut exists when any part of the male mold master tucks back under the bottom edge of the object as it sits on the peg board in the well. Essentially, an undercut will keep the male mold master trapped inside the plastic copy. For example, a solid cylinder on its side cannot be vacuformed, because it will not be releasable from the mold. The plastic would be vacuformed to the underside of the cylinder and thus be clamped around it. A solid cylinder cut in half lengthwise and placed cut side down would work because there is no undercut. For this article, a shape that would look good as a panel on a robot was selected, and this ideal male mold master turned out to be a kippered herring container. It has an interesting shape, and it is the right size. Additionally, it has a flat bottom that does not need to be adapted for use in the vacuform box. Do not use anything for the male mold master that is affected by heat, such as wax.

The sharp detail will always be on the inside of your casting when male mold vacuforming. Finely detailed lines will not show. This is also, strangely enough, an advantage, since you can use several materials to make one integrated mold, such as metal, plastic, wood, and so on. The vacuformed casting will be smooth and uniform in appearance on its outer surface. You could even have a mold that's a bit rough. Just paint the copy and the part will look fine.

The Moment of Truth

Everything is assembled. The vacuform box is ready beside the oven, and the vacuum's hose is installed. Place the part to be molded in the center of the vacuform box (see Photo 5). Be certain that it sits flat against the pegboard. If it does not sit flat, use some modeling clay to fill any undercuts, and that should provide the finishing touches to mold master preparation. Arrange the oven rack so that it's on or near the bottom of the oven. Place the holding frame with plastic on the standoff in the middle of the rack (see Photo 4). Set the temperature at 350° F. A lower or higher temperature may work better, but start out at 350° F. Allow time for the oven to warm.

Cut out a piece of plastic to fit the holding frame. Plastic builds static electricity that attracts hair and lint. Vacuum the plastic well on both sides. Place the plastic between the two halves of the holding frame, clamp it, and place the frame on the standoff in the oven.

Do not melt the plastic; it only needs to get soft. Opening the oven and tapping the plastic is one way to tell if it's getting soft. The plastic will begin to droop in the middle. Drooping indicates softening and thinning of the plastic material. Different projects will need different amounts of droop. The less droop the thicker the material and the higher the quality of the copies. The better the vacuum, the less

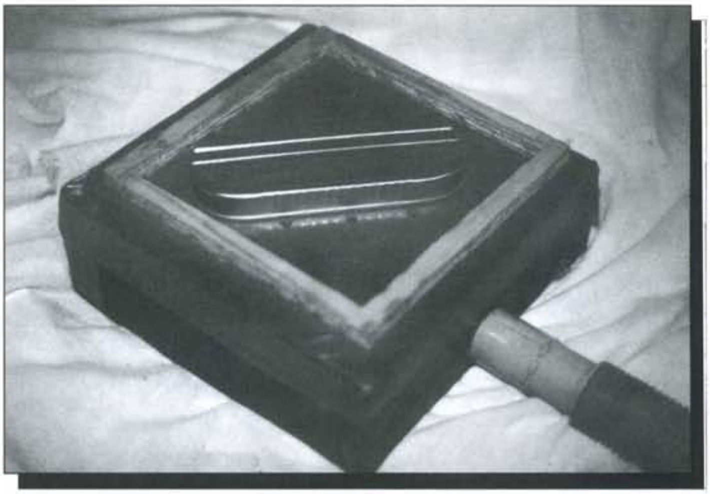


Photo 5: The original placed in the vacuform box.

plastic droop you need. A powerful vacuum cleaner comes in handy. It can be hard to tell when you have enough droop, or even to see the droop at all. It is helpful to draw an "x" across the top of the plastic before heating. The "x" makes it easier to track the softening and drooping process.

Please note that you can't use a stopwatch to time how long to heat the plastic. Observe the plastic each time you soften it. Ovens differ in the time it takes to heat pieces of plastic. The heating time for one casting may not be appropriate for the next. After establishing how much droop is required, stick with that for each copy from the same mold.

Occasionally, the plastic will pull away from the edges of the frame. When this happens, scrap the plastic. Cut a piece slightly larger than the holding frame and clamp the frame tighter on the plastic. Try adding some spring clamps on the areas where the plastic is pulling out. If none of these efforts work it may be necessary to redesign the frame.

When the plastic appears soft enough (for a small project, it should take less than a minute), take the frame out of the oven and place it over the vacuform box (see Photo 6). Turn

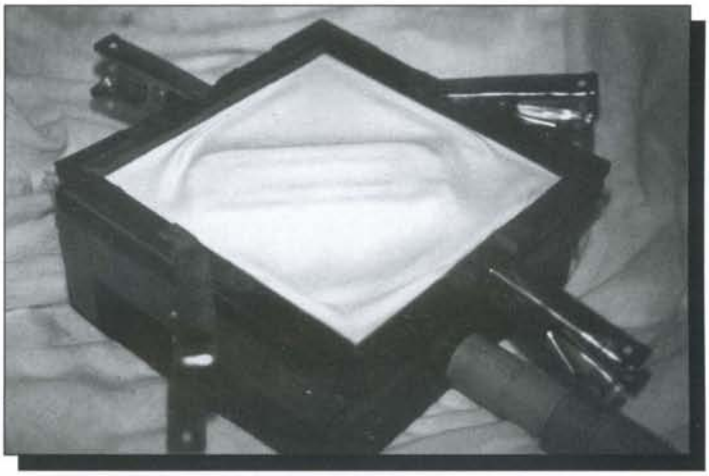


Photo 6: The softened plastic, just before the vacuum is turned on.

Photo 7: *Voila! A couple of seconds later, and the piece is formed.*

on the vacuum and in a second or two the plastic will have formed to the mold (see Photo 7). This transformation is truly magical, and in over ten years of vacuforming, I have never tired of the sight.

One thing to consider during this process is when to turn off the vacuum. Carefully observe the piece; if there is no change, shut the vacuum off (generally after a few seconds). It won't hurt anything to keep it on longer, but it won't help either. Look at the cast part. A true strength of vacuforming over other methods of plastic casting is the immediate results. Mistakes can be corrected almost at once. Did the plastic form around the mold well? If not, try using more droop the next time. Are there areas outside the casting where the plastic folded? Try placing some clay on the pegboard in the box, and placing your mold on the clay.

I actually performed all these steps as I described them to you, and for this demonstration, the plastic molded to the master quite well. The master popped out nicely. This is the sign of a good casting. If it had been difficult to get out, that would have meant an undercut in the master. If the casting just came off with no effort, the plastic probably hadn't drawn tight enough to the mold.

Notes:

Some plastic sheets vacuform well, and some don't. Most sheets have two different surfaces, one matte, and one glossy. Try one side down against the mold and then the other. Sometimes, that can make a difference. Some plastic sheets have a film on them, which can lead to holes forming in the plastic while it's softening. There is nothing to be done about this since the film is part of the plastic making process. Sometimes the film is visible (sort of a light gray), but sometimes it is not. If the plastic starts developing holes then the film was there.

Standard model making methods work fine for cast pieces. Anything you can do with a plastic part from a model kit can be done with vacuformed pieces, such as sanding, gluing, puttying, painting, etc. The basic method for cutting vacuformed pieces is simple: Cut them slightly larger than needed, and then sand them to shape. Super glue works well for vacuformed pieces, and Micro Weld works too.

There are more complex and expensive vacuforming methods. Purchasing or making a vacuform machine, measuring the amount of vacuum, or making a two-stage vacuum pump are just a few ways to increase the complexity and expense. I have vacuformed for about a decade using nothing more complicated than the basic tools discussed above, and been pleased with the results. Vacuforming can be fun, and a quick and inexpensive method for making your robot an ***awesome beauty to behold.***

It is strongly recommended that an electric oven be used for this process.

EXERCISE EXTREME CAUTION

Use plenty of ventilation, and follow directions on all labels. Use common sense and wear heat-insulated gloves when handling hot materials, and when removing the holding frame with the plastic from the oven.

RS&T

Resources

The Prop Builder's Molding and Casting Handbook, by Thurston James (1989, Betterway, $19.95)

A good overview of molding and casting. I built the vacuform machine described in this book, but it's actually too large for my use. I prefer working with the oven and vacuum cleaner method.

Do It Yourself Vacuum Forming for the Hobbyist, by Douglas E. Walsh (1990, Vacuum Form, $9.95)

This goes into an incredible amount of detail. If you want to go beyond the methods in this article, this is the book to get.

***Flint Mitchell** has been involved in the science fiction community for 20 years. Starting with general science fiction fanzines, he eventually ventured into his forte, LOST IN SPACE fandom, in 1981. Over the years, Flint has published several books, including This is Not a Chain Letter! (1990), "The Complete LISFAN" (1991) and perhaps his best known work, You Can Build... the LOST IN SPACE Robot (1997). Flint is now currently working on another book, The LOST IN SPACE Encyclopedia, which will hopefully be out within a year. When not working on LOST IN SPACE projects, Flint dabbles in low budget film making and building stereo speakers.*

"The Toyship" by Charlene Taylor D'Alessio

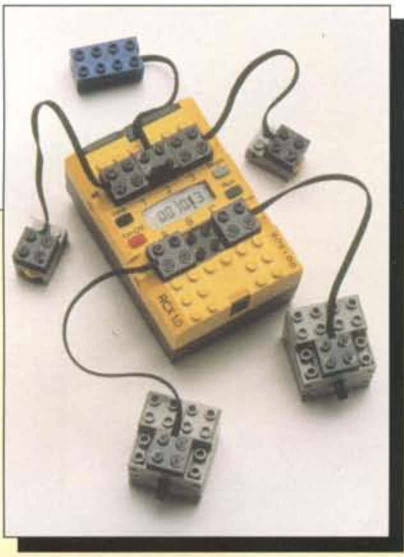
21st Century Robot Showcase

During the Holidays, Most of Us Generously Spend Money. Is Anyone Investing in Their Future?

Affordable Robots and Robot Kits Are Ready for Prime Time, and have been for years, but the shopping public rarely sees them. So we at Robot Science & Technology decided to showcase a few systems that will appeal to just about everyone. We're only sorry we don't have enough pages to bring you dozens more. RS&T invites you now to find your robot on the following pages.

LEGO® MINDSTORMS™

Robotics Invention System™



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Program the RCX™ autonomous LEGO microcomputer using a PC.

Includes over 700 LEGO pieces, the RCX microcomputer, infrared transmitter for downloading programs, CD-ROM, light and touch sensors, motors, gears and a Constructopedia building guide. Build working robots in under an hour. About $200. Expansion Sets retail for about $50.

Available at many major outlets, including Toys Я Us, Target, Fry's, FAO Schwartz and Mondotronics' Robot Store catalog.

www.LEGOMINDSTORMS.com

Rug Warrior Pro & Mobile Robots:

Inspiration to Implementation

This robot kit and how-to book give you insider knowledge from MIT's Artificial Intelligence Laboratory

Mobile Robots: Inspiration to Implementation was written by Joseph Jones and Anita Flynn, both formerly with the MIT AI research staff, and educator Bruce Seiger. It is a guide for construction of the *Rug Warrior Pro* robot kit, and the authors created the book and kit as a matched pair.

Rug Warrior Pro is more than a teaching aid; it is able to support real applications. It is configured with the Motorola MC68HC11 microcontroller, and it can be upgraded. One significant upgrade is the Stackable Expansion Module (SEM) standard. This circuitry makes it easy to add new memory-mapped sensors and actuators, and additional functionality can simply be plugged in to *Rug Warrior Pro*. Documentation supplied with the kit provides information that enables users to construct their own SEMs.

Several SEM kits are available for *Rug Warrior Pro;* the *RugBat* sonar module gives *Rug Warrior Pro* the ability to measure distance; *RugIO* adds eight digital input lines and eight digital output lines; *RugTalk* gives *Rug Warrior Pro* the ability to speak, and *RugEx*, the experimenter's board, provides a prototyping area where builders can construct their own circuits.

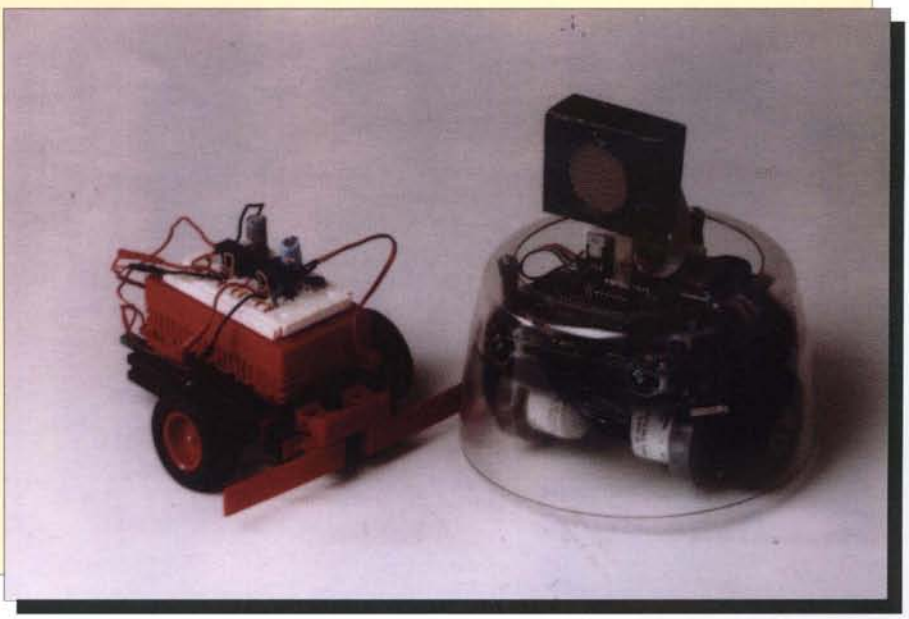
Rug Warrior Pro is a second generation robot, and owners of the original *Rug Warrior* can attach SEMs by first installing an available *RugUp* upgrade board.

The book is priced at $32 + S/H, and the robot kit at $595 + S/H

Mobile Robots: Inspiration to Implementation and Rug Warrior Pro are available from

A K Peters, Ltd.
63 South Avenue
Natick MA
01760-4626

Phone: 508.655.9933
Fax: 508.655.5847
www.akpeters.com
service@akpeters.com



Introducing Cye

This innovative robot, an invaluable helpmate for home or office chores, comes out of the box ready to roll

There aren't many robots that perform household tasks, but that has changed with the introduction of *Cye*. This robot uses graphically-oriented software and industrial design to redefine practical robotics. You map the robot's environment directly to a PC: Click and drag the *Cye* icon, the robot moves in concert, mapping the area to memory. You label the map with room and location names, "off limit" areas, and calibration points. Command *Cye* to go to a location by name, and the robot will comply.

An available wagon has a capacity of up to 4.5 kg, or *Cye* can easily pull a vacuum around a mapped "vacuum patch." It has an obstacle avoidance feature; if an obstruction is encountered, *Cye* goes around and marks it on the map.

Cye's sealed 12 Volt, rechargeable battery provides power and endurance. In its premier public demonstration, the robot performed for over six hours without a recharge.

The robot has a mount for wagon, vacuum or other hardware add-ons and an RJ-45 port with +12V, +5V, ground and serial communications to the PC. The standard software has a complete set of Active-X controls that allow you to operate *Cye* with your own Visual Basic or C programs. The fully assembled, tested robot comes with a home-base charging and control station.

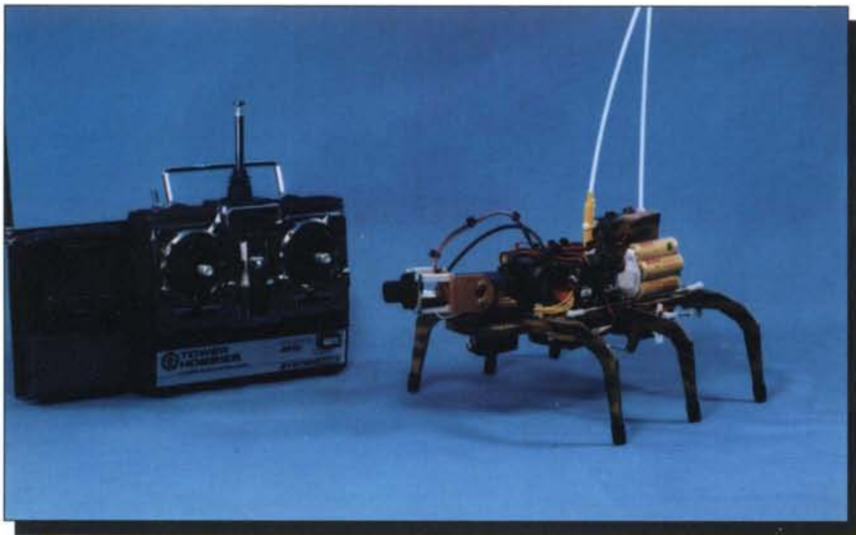
Specifications: Radio control link, 900 MHz (FCC-approved); Size - 40 x 28 x 13 cm; Weight - 4 kg; PC Requirements: Pentium 90 MHz (or better), Windows 95 or 98, CD-ROM drive, Serial Port.

Cye has a tough plastic shell, and comes in three color combinations - orange and black, yellow and gray, and black and green. The basic *Cye* has a list price of $695, which includes the charging station, radio link, PC cable, AC adapter, software and a one-year manufacturer's warranty. Not included are the vacuum, the wagon, and their attachments.

Cye is available from

Mondo-tronics, Inc.
4286 Redwood Highway #226
San Rafael, CA 94903

Phone: 415.491.4600
Fax: 415.491.4696
info@mondo.com • www.RobotStore.com
800.374.5764 / 9 AM-6 PM Pacific



A Hexapod Walker Kit for Your Expanding Imagination

Of all the machines called "robots," perhaps the most interesting are six legged walkers, because they just look so cool

A properly constructed and programmed hexapod walks with a decidedly life-like gait. With a hexapod kit, you can make simple or complex robots, from rovers with bumper-avoidance, to zero-contact infrared and proximity sensor-equipped follow-and-avoid projects.

The Lynxmotion *Hexapod Walker* Kit is a high-quality yet affordable robot, providing expendability to match your imagination. Practical-minded, entrepreneurial engineers will find the *Hexapod* kit to be an excellent instrument for proof-of-concept prototyping of heavy metal commercial products.

For instance, the photo shows a *Remote Piloted Hexapod* Project. As the name implies, it is a robot that can be remotely maneuvered by radio control. The foundation of the project is a build-it-yourself *H1-KT Hexapod* Kit. To modify the *Hexapod* as shown in the photo, you'll probably spend about ten hours in construction time, and about $500 for the modification materials, such as a video camera, a transmitter for audio and video, a pan and tilt head, and a remote control receiver. In the end, you'll be richly rewarded with a congratulatory "well done" from your labmates and friends.

Lynxmotion provides both stationary and mobile robot kits. The *H1-KT,* which is the basis for the project in the photo, is available from Lynxmotion for $150.

Lynxmotion, Inc.
104 Partridge Rd.
Pekin, IL 61554

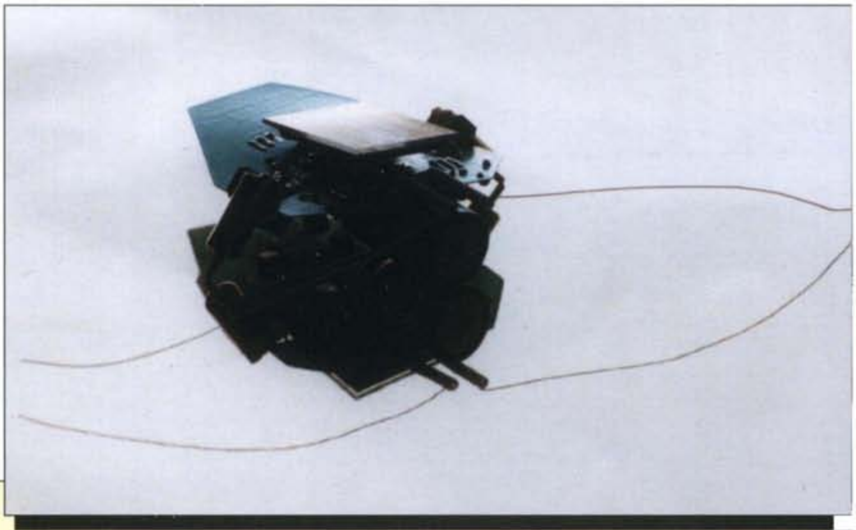
Phone: 309.382.1816

Fax: 309.382.1254

www.lynxmotion.com

Sales@Lynxmotion.com

The Photopopper© Photovore Robot From Solarbotics



A cool little robot you can build that is powered by light

Like most BEAM (Biology, Electronics, Aesthetics, and Mechanics) robots, *Photopopper* uses a pair of simple solar engine circuits to receive light energy from its solar cell, and periodically sends power pulses out to its motors. A simple, elegant robot, it is light seeking, obstacle avoiding, and battery-less.

Photopopper does not require a microprocessor, and there is no need for programming - its behavior is built-in and tunable with a screwdriver. Its brain uses simple, powerful electronics, that naturally attract it to light, the source of its power. Photodiodes are used to assess and locate the best source of light, it then faces the source and heads toward it, avoiding shadows. You can "herd" the robot in any direction by merely casting a shadow!

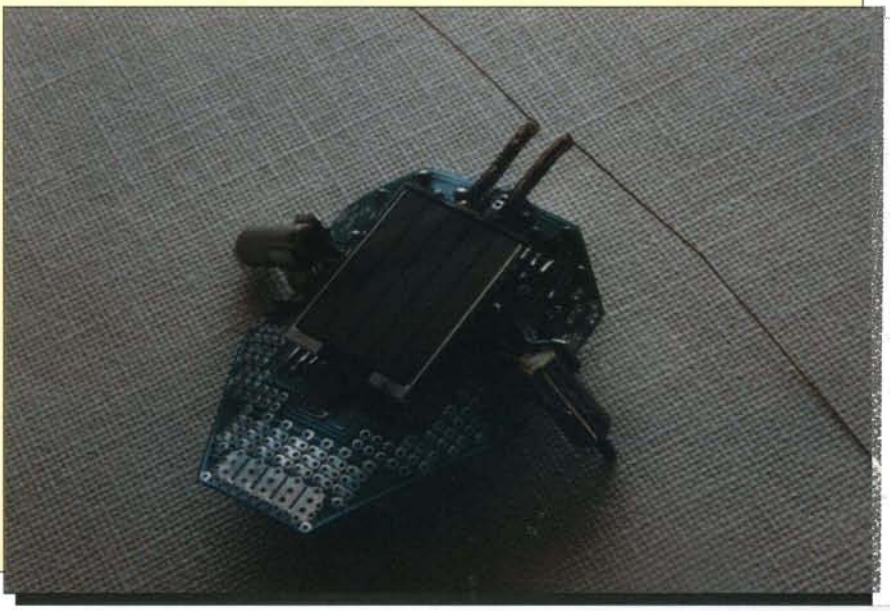
Tactile sensors allow it to feel its way. Should it bump into an obstacle, the sensors override its light-seeking behavior, it turns away and continues on its journey to the land of light!

Direct sunlight will allow *Photopopper* to travel one meter in under a minute. If you can read a newspaper, the robot can keep moving. Only darkness can keep it from accomplishing its mission - to get closer to sources of light! *Photopopper* does not have an off switch, so don't leave it on a tabletop - you'll find it on the floor when you come back!

Excluding damage from pet cats, falls from tabletops and other unforeseen events, *Photopopper* should have a lifetime ranging in the tens of years. With no battery to replace or recharge, the robot should continue to function for quite a long time. Try having *Photopopper* drag a pencil on a sheet of paper so you can track its behavior. Or have two of them contest for the same spot of light!

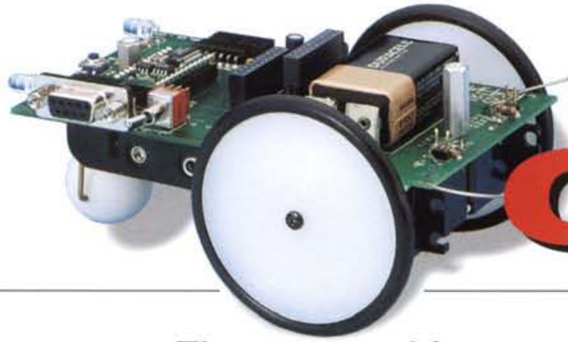
Photopopper 4.2, priced at $60 + $6 S/H, is a great way to break into the world of BEAM robotics.

Photopopper©Photovore is available from



Solarbotics, Ltd
179 Harvest Glen Way N.E.
Calgary, Alberta
Canada T3K 3J4

Phone: 403.818.3374
Fax: 403.226.3741
www.solarbotics.com



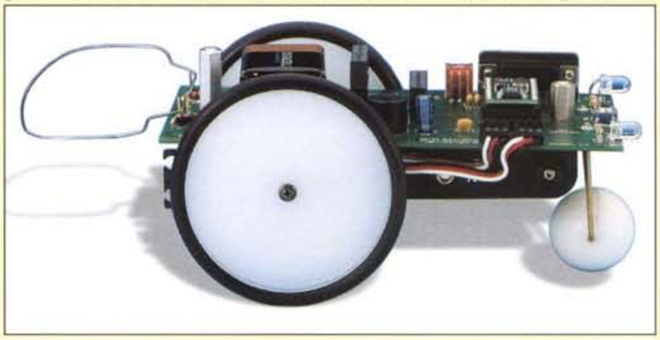
Meet GrowBot!

The open architecture of this affordable robot kit lets you add applications, and its capabilities grow with you

The Parallax *GrowBot*™ is a small robot with many features. Controlled by the Parallax BASIC Stamp™ II module (BS2-IC), it uses radio-control servos for propulsion, and a quality PC board as its chassis. In addition:

It has growth potential; the BS2-IC gives the *GrowBot* input/output I/O expandability. The PC board has six re-configurable I/O pins for bumper switches, phototransistors, and other sensors and outputs.

GrowBot is easily programmed to do light-following, obstacle avoidance, and sound broadcasting. With additional programming, it can follow walls, run mazes, and track lines. Seven I/O pins are available for other uses. Two expansion connectors carry sixteen Basic Stamp pins, plus power and ground.

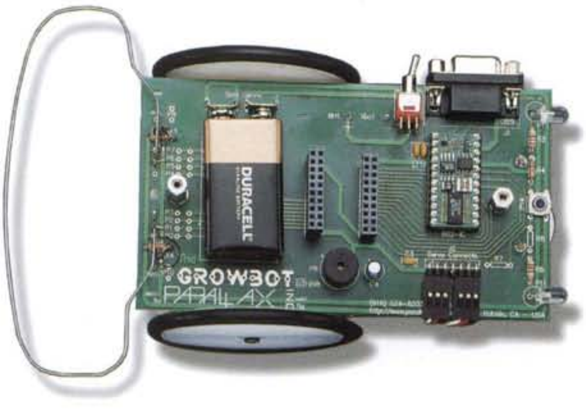


Parallax designs are flexible. Expansion headers are used for stacking Parallax application modules. These provide breadboard and prototype areas for your use. The Parallax BASIC Stamp Activity Board and Board of Education can also use these modules.

Test GrowBot during assembly using software preloaded in the BASIC Stamp. When complete, it will run in the obstacle avoidance, roving mode. For programing, the kit includes the BASIC Stamp Windows© editor and several samples. Documentation includes source code ideas and tips. See Parallax's web site for the complete PBASIC and BASIC Stamp Manual and Application Notes (Version 1.9).

The *GrowBot* kit ***makes a great parent-child project***, and is suitable as a solo project for older children. All components required for completion (except for batteries, solder, and simple hand tools) are provided.

GrowBot is available at a special introductory price of $149.



GROWBOT

See our ad on the back cover of this issue of RS&T.

Available from Parallax, Inc.
3805 Atherton Road,
Suite 102, Rocklin, CA 95765

Phone: 916.624.8333 • 888.512.1024
Fax: 916.624.8003
www.parallaxinc.com

Edurobot

The RB5X Educational Assistant Robotics comes to the Classroom

An educational tool capable of increasing attention, comprehension, and motivation for learning – the *RB5X Educational Assistant*, "*Edurobot*." Mathematics, science, language arts, social studies, and computer technology are enhanced at all grade levels. In a controlled study, sixth graders were found to increase their math comprehension by 40% in just six months.

The *Edurobot* excels in helping students learn English as a second language. It becomes the student and children increase their language skills by teaching it to speak. This principle, students as teachers, requires students to demonstrate their knowledge and identify their learning gaps. Unlike a computer or robotic arm, the *Edurobot* interacts with your class, developing self-esteem and problem solving skills, critical in today's world. Thus, students take responsibility for their educational experiences and gain life-long motivation for learning. As an integral part of the learning experience, *Edurobot* is in schools in all 50 states and countries around the world: Canada, Mexico, Kuwait, Singapore, Japan, France, England, South Africa, Norway, and Germany.

The *Edurobot* is versatile, incorporating infrared sensing, ultrasound sonar, remote audio/video transmission, eight sensors/bumpers, voice synthesizer, and a five-axis armature for lifting. In addition, it can play interactive games with up to eight people.

The *RB5X Educational Assistant* "*Edurobot*" is available from:

General Robotics Corporation

Phone: 800.422.4265
Fax: 303.988.5303

www.edurobot.com
www.generalrobotics.com

Ancient Words of Wisdom for Modern Robot Battles

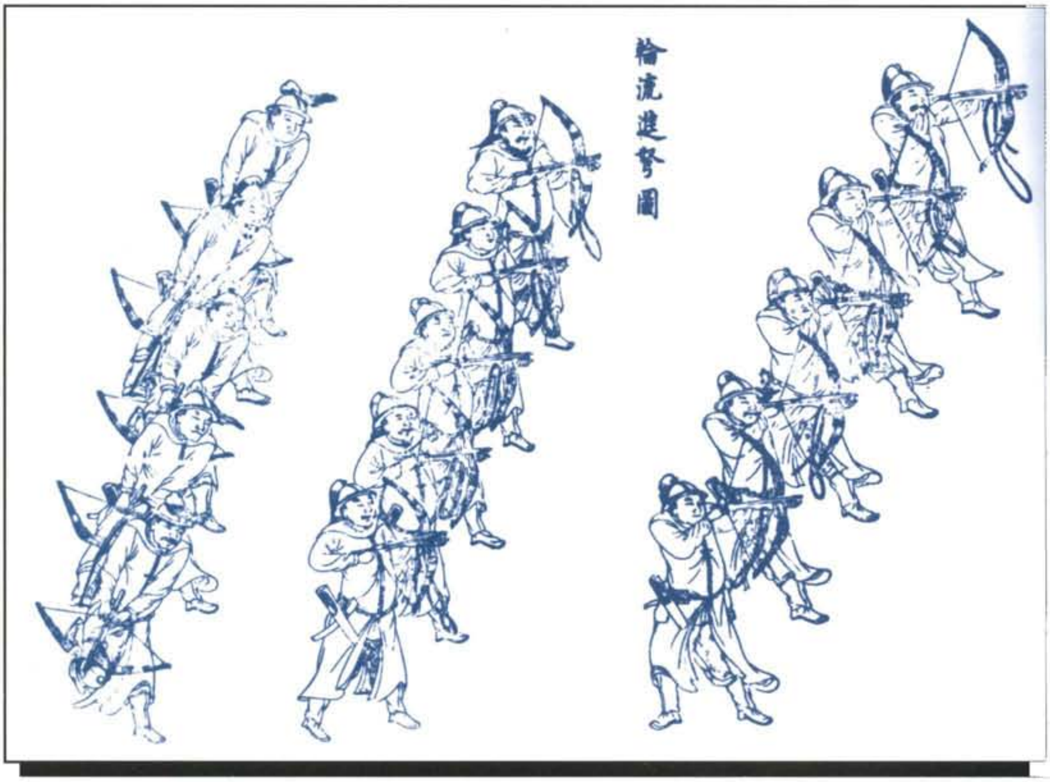
The Art of Robot War

History is replete with examples of battles fought. Seldom did these battles end in a draw; there were the victors, and there were the vanquished. A common denominator of war is that all battles have combatants, and ***Robot warriors*** represent a continuation of this basic truth. Builders of fighting robots can learn a great deal from history as they prepare their creations for combat. If fact, if you **Heed the words of Sun Tzu,** as interpreted by Carlo Bertocchini, **your warrior can emerge victorious.**

by Sun Tzu and Carlo Bertocchini

Over two thousand years ago Sun Tzu, a Chinese warrior-philosopher, wrote *The Art of War*. The lessons in that book can be applied to a wide range of modern day problems. Business managers scour the book for lessons in business administration, politicians use the teachings to outmaneuver their opponents, and the military still finds some important lessons in *The Art of War*. With such wide-ranging utility, it would be surprising if there wasn't a lesson or two for those involved in a robot competition. Imagine that instead of a great warrior, Sun Tzu was a champion robot wrangler who penned wise and poetic lessons about the art of robot war. What was he trying to tell us aspiring robot champions? Sun Tzu's words are in Italics.

Preparing for Battle



He whose ranks are united in purpose will be victorious.

Robots can be constructed by one person, but the rising level of competition will soon make this difficult or impossible. This is especially true because of the many disciplines that must be mastered. A robot project will require expertise in electronics and mechanics. If the competition is for autonomous robots, then knowledge of computer hardware and software will also be essential. The easiest way to gather this knowledge is to form a team of people who already possess it, however that may not be enough. Sun Tzu warns us that we must be *united in purpose*. Building a competition robot requires a great deal of time and commitment. In the heat of intense competitive pressure, it is possible—even probable—that some disagreements and friction will arise among the team members. The "general" must make sure that a prospective teammate is capable of, and willing to make, the contribution that will be required of him. If there are any doubts, then it might be best to continue the search for a more ideal partner.

To prepare the shielded wagons and make ready the necessary arms and equipment requires at least three months.

Sun Tzu meant to say "robot" here instead of "shielded wagons." Let's overlook his little mistake. While it is possible for an experienced builder to throw together a decent robot in a few weeks, "decent robots" don't usually win competitions. If your goal is to win, then strive for an excellent robot. It is no secret that building an excellent robot can take a tremendous amount of time. Three months may sound like a long time, but several amateur robot projects have been known to take three years or more. The trick is to start early. Tzu has more to say on this:

Thus a victorious army wins its victories before seeking battle; an army destined to defeat fights in the hope of winning.

Two thousand years ago Sun Tzu knew that a competition was won or lost before the opponents set foot (or wheel) in the arena. If you send an ill-prepared robot into battle, your only hope of winning is an opponents malfunction, or a great stroke of luck.

Those skilled in war cultivate the Tao and preserve the laws, and are therefore able to formulate victorious policies.

After gathering your team and allocating sufficient time for the effort, your next step is to study the law (the rules). The team must find and utilize every possible advantage in the rules, while making sure that they *"preserve the laws."*

I was captain of a team that entered the 1995 For Inspiration and Recognition of Science and Technology (FIRST) competition (www.usfirst.org). Our team was composed of about five engineers and 15 high school students, and had a strict time limit for preparing a robot for competition. Teams had seven weeks from the release of the official rules at the kick-off to complete their robot. The rules were faxed from the United States FIRST headquarters to teams throughout the nation. Our team was anxiously waiting by the fax machine, ready to start designing and building. The first pages came and were quickly copied and given to each team member. We started to read the rules. The fax machine kept printing. An uneasy feeling came over me. Why is that fax machine still running? Are they sending the rules twice? When the machine finally stopped buzzing almost an hour later, a very thick stack of paper rested in front of us.

The team is the answer

Our team spent two precious days studying the rules. The contest was a complicated affair. Robots that weighed no more than 80 pounds were required to grab huge rubber balls, and race across the field over a speed bump. Then they were to climb one of three eight-foot ramps to reach the scoring platform, and swing the ball back and forth over an eight-foot tall goalpost. The robots would compete three at a time, and the team that scored the most "goals" won the match. Our team did many things just right (and a few not quite so right) in preparing for this difficult competition. Still, I believe a thorough and deep understanding of the rules was an essential element in our success.

One who has few must prepare against the enemy; one who has many makes the enemy prepare against him.

Scholars might disagree with my interpretation, but I believe that Sun Tzu was talking about money. Many robotic competitions can be entered on a shoestring budget. Some examples are the Biology, Electronics, Aesthetics, and Mechanics (BEAM) (sst.lanl.gov/robot/), and Robot Sumo (www.robots.org) competitions. Other competitions will require a substantial financial commitment. According to the most recent accounting, *BioHazard*, a heavyweight battle robot, had topped the $8,000 mark, and many of its opponents have cost even more, in some cases much more. If you are "*one who has many*" then you will have a much easier time preparing against the enemy. If you have a tricky bit of machining to do, you could give the job to a machine shop. If your heart is set on that "ultimate" motor, just write a check! If you are "*one who has few*" then you will have to work a little harder and/or smarter to prepare against the enemy.

Designing the War Machine

Robot technology has changed in the past 2,000 years, but some design tips have stood the test of time – strength, speed, and agility.

Z's power and speed let it pop wheelies and zigzag on a dime. Tracked heavyweight RC warrior by Vic Lang of Z Interactive. Photo by Dean Thomas Photography, L.A.

Invincibility depends on one's self; the enemy's vulnerability [depends] on him. It follows that those skilled in war can make themselves invincible but cannot cause an enemy to be certainly vulnerable. Therefore it is said that one may know how to win, but cannot necessarily do so. Invincibility lies in the defense; the possibility of victory in the attack.

This advice is especially important in competitions that include *destructive* battle robots. Here Sun Tzu is talking about the delicate balance that you must achieve between your offensive and defensive capabilities. Since these competitions impose a maximum weight limit on your robot, the creative designer must decide how to divide this weight budget between offensive weaponry and defensive armor. A robot optimized for defense may be invulnerable, but it "*cannot cause an enemy to be certainly vulnerable.*" You must allocate some of the weight budget to offense, but if you go too far, you may not be able to armor properly all vulnerable areas of your robot.

If he prepares to the front his rear will be weak, and if to the rear, his front will be fragile. If he prepares to the left, his right will be vulnerable and if to the right, there will be [weakness] on his left.

Those of us struggling with the weight problem should be heartened to learn that we are not the first ones to face this. Our brothers half a world away, and over 2000 years in the past, had to deal with the same problem.

Speed is the essence of war.

We can design our robot for speed or pushing power, but unfortunately, we can't have both at the same time. Modern speed reducers (gears, chains, and belts) can multiply the torque produced by our motors, but only at the cost of reduced speed. Optimal speed for your robot depends on many factors; weight, size of the battlefield, horsepower available, speed of the opponent, etc. How much pushing power the robot needs is somewhat easier. It boils down to how much power it can use to

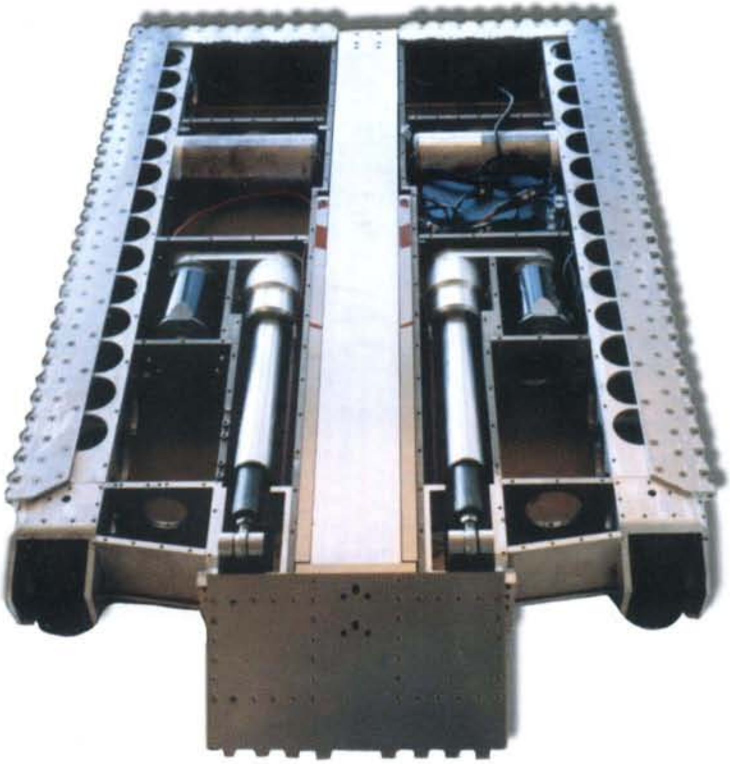
Gladiator II wields a pivoting electric chainsaw. Infrared target beacon on top. Laptop 386 under the hood. Fully autonomous attacker by Camp Peavy of Intuit. Photo by Dean Thomas Photography, L.A.

advantage. In other words, what is the maximum torque deliverable to the drive wheels before they spin ineffectually. A rule of thumb is to use a gear ratio that will multiply the torque from your motor to the point that the drive wheels will just break traction. Any gear reductions beyond that will reduce the top speed without gaining an offsetting increase in pushing power.

Nothing is more difficult than the art of maneuver.
Most competition robots use tank-style steering. They have no wheels that are steerable like the front wheels of an automobile. This simplifies the mechanical design and enables the robot to turn on a dime. The disadvantage of this setup is that it is sometimes difficult to remotely control the robot. For the robot to travel straight, the motor driving the left wheel(s) must turn at exactly the same speed as the motor driving the right wheel(s). This is a trivial task for a robot controlled by machine intelligence, but it can be very difficult for a human controller. Control of turning can also be difficult. In 1996, I entered a robot with tank-style steering in a competition. My robot, *BioHazard*, had four-wheel drive. This made it sluggish when turning because turns required the wheels to break traction and skid (tank-style steering is sometimes called skid steering). However, this also had the advantage of better straight-line control because of the same skidding phenomenon. In 1997, the robot was changed from four-wheel drive to six-wheel drive. This greatly increased the maximum rate of turn. It also had the unfortunate and unanticipated effect of reducing straight-line and turning controllability. For instance, if the robot were resting on a bump with just the two center wheels touching the ground, it would turn at the slightest nudge of the joystick. On the other hand, when the four outboard wheels where resting firmly on the ground, the robot would revert to its old sluggish turn rate. There are technical solutions to this problem, but don't forget the old standard: practice, practice, practice.

Battle Tactics

Victory is the main object of war. If this is long delayed, weapons are blunted and morale depressed...Hence what is essential in war is victory, not prolonged operations.



The powerful heavyweight champion, BioHazard lifts opponents off the floor. Fully electric RC robot by Carlo Bertocchini, co-author of this article and president of RobotBooks. Photo by Dean Thomas Photography, L.A.

You should decide if the first sentence in the above passage applies. Is victory your main objective? Many things might motivate you to enter a robot competition besides victory. This is not necessarily bad, but it is something that should be made clear before you begin. You might enter for the learning experience, you might do it for fun, or maybe you have an idea for a robot that would impress the audience. If victory is not your main objective, you don't have to worry about Sun Tzu's admonition against prolonged operations. However, if winning is your goal, you must use your strength, speed, and agility to get the job done with a minimum of theatrics and grandstanding.

It is impossible to know too much

Generally, in battle, use the normal force to engage; use the extraordinary to win.

I wish I had been familiar with this bit of advice in the 1996 competition. I had been working on *BioHazard* for several months, and had just perfected the powerful arm that could easily scoop up a 170 pound opponent and leave it overturned and immobile. The battles went very well as one by one the other robots succumbed to the power of this new and unexpected weapon. After a long and perilous battle with the final opponent, *La Machine*, *BioHazard* maneuvered into position, extended the arm and lifted the other robot. *La Machine's* protective armor went up but the rest of the robot remained on the ground. Vital mechanical components had broken leaving *La Machine* immobile! *BioHazard* took the prize for the one-on-one competition, and we prepared to battle for the melee prize. In the melee competition, several robots (typically six) go into the arena at the same time; the last one moving wins. The "normal force" of *BioHazard* is its low center of gravity and pushing power. Its "extraordinary" force is the arm. I should have engaged the enemy with my normal force as Sun Tzu suggests; instead, I attacked with the arm. The arm is vulnerable when not in its protected retracted position, so it didn't take long for one of the robots to score a crippling blow. The arm bent and would no longer retract. In the heat of battle I forgot to release the retract button and as a result, the motor, the electronic speed controller, and about six feet of heavy gauge wiring all went up in a big ball of smoke. The melee trophy would not be mine that year, but in '97 I heeded the Great Man's advice. I used the arm only to clinch the win, and *BioHazard* ended up with both the one-on-one and the melee trophies.

Know the Enemy

Now the reason the...wise general's...achievements surpass those of ordinary men is foreknowledge. [It] cannot be elicited from spirits, nor from gods, nor by analogy with past events, nor from calculations. It must be obtained from men who know the enemy situation.

In the 1995 FIRST competition mentioned above, our team had exactly seven weeks to finish its robot and ship it to Disney World where the competition would be held a month later. Some teams were participating in a regional competition, and they had their robots for an extra week or so before they were required to ship them to Florida. Although it was too late to make changes to our robot, we were very keen to get a glimpse of the enemy before going into battle.

Unfortunately, the venue for the regional competition was about 2000 miles away. Over budget on the robot, and with travel expenses for 13 team members coming up, we couldn't afford to send a spy to the regional. However, we *could* afford to make a few telephone calls to find someone who would videotape it for us. The tape was grainy, the action poorly lit, and the subjects sometimes out of focus. But we watched it repeatedly, freezing the action on key frames and studying it as if we were the FBI studying the Kennedy assassination tape. We wanted to:

BuzzCut climbs atop opponents and rips them apart with gas weedeater-powered circular saws. Eight-legged RC walker by Christian Carlsberg of Walt Disney Imagineering. Photo by Dean Thomas Photography, L.A.

Probe him and learn where his strength is abundant and where deficient...determine the enemy's plans and you will know which strategy will be successful and which will not. Take advantage of the enemy's unpreparedness...and strike him where he has taken no precautions.

The national competition at Disney World was a two-day event. The first day was for seeding matches. Each robot was matched against six others randomly chosen from the dozens of competitors. We had learned the strategies, strengths, and weaknesses of about one-fourth of the robots. Now was our chance to fill in the gaps in our knowledge. The pace was hectic and most of the team were either preparing or repairing the robot all day. We staked out some front row seats and, working in shifts, had at least two team members taking copious notes on each of our opponents. We learned which were fast and which were slow. If the opposing robot was a strong ramp-climber, but a weak ball handler, we would adjust our strategy. If the robot had a tendency to fall off the ramp, we would be there to give it a little nudge. We won every match that day and were awarded the trophy for top seed. The next day, with the help of our database of enemy intelligence, we won the competition! After a performance like that, they couldn't help but give us the trophy for Rookie of the Year. We may have taken it to an extreme, but we firmly believed in this advice from Sun Tzu:

Know the enemy and know yourself; in a hundred battles you will never be in peril. When you are ignorant of the enemy but know yourself, your chances of winning and losing are equal. If ignorant both of the enemy and of yourself, you are certain in every battle to be in peril.

Of course this foreknowledge business can be a two edged sword. You should take precautions that your own secrets do not fall prey to the enemy spies. Remember:

All warfare is based on deception. Therefore, when capable, feign incapacity... Pretend inferiority and encourage his arrogance.

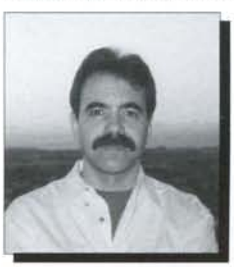
These lessons have not been lost on modern day robot warriors. If you search the Internet, you will find many pictures and descriptions of competition robots. You will also find that some people are not so forthcoming with details of their design. Some offer only tantalizing hints of the capabilities of their robots. Photographs provided are extreme close-ups or distant and unfocused—just enough to portray a serious competitor, but not good enough for a spy to gain an advantage. In at least one case, a competitor who was well respected and feared had posted monthly construction updates on his web page of what looked like a formidable robot. One month before the competition he posted an update that told a horror story about how nothing was working and how he was having trouble finishing the robot. This was in fact a ploy to throw the competition off its guard, and it worked. He went on to win the event.

RS&T

Resource

A great source of books about robots is www.RobotBooks.com. In addition, on the Internet at www.RobotBooks.com/ArtofWar you will find the complete text of "The Art of War" by Sun Tzu (Hidden to all except the readers of this article).

Carlo Bertocchini *is a mechanical designer from Belmont, California. His robot (BioHazard), has been the heavyweight champion at Robot Wars for the past two years. He was the captain of the winning team in the 1995 FIRST robot competition at Disney World, and his robot Sumo wrestler (Beast), has been undefeated since it was born in 1994. He can be reached at "www.RobotBooks.com".*



1999 FIRST Robotics Competition Schedule

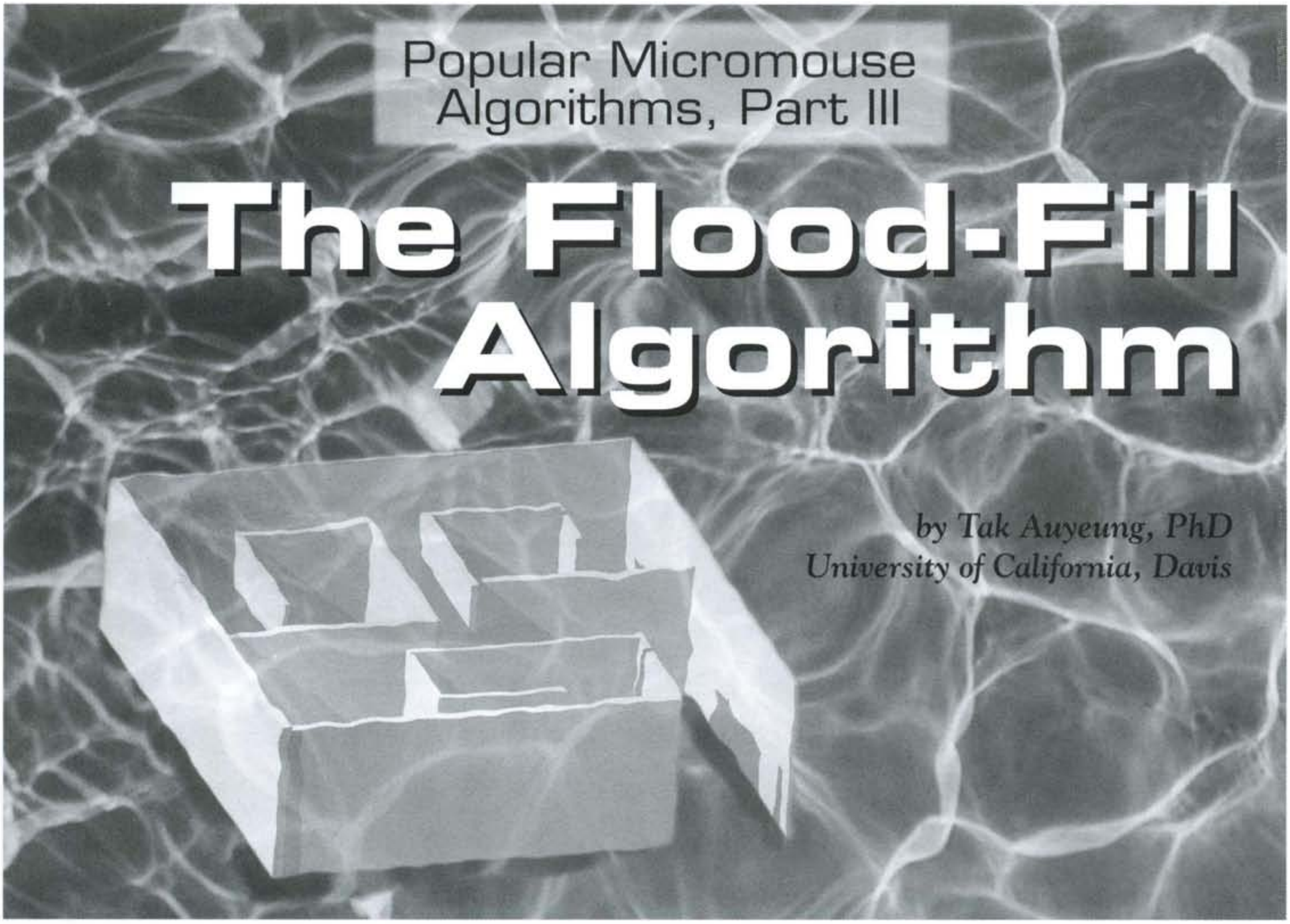
www.usfirst.org

NASA Ames Regional **Research Center**	**February 25 – 27, 1999** **Moffett Field, California**
Motorola Midwest Regional **William Rainey Harper College**	**February 25 – 27, 1999** **Chicago, Illinois**
Kennedy Space Center Regional **Kennedy Space Center**	**March 4 – 6, 1999** **Kennedy Space Center, Florida**
FIRST Southwest Regional **Space Center Houston**	**March 4 – 6, 1999** **Houston, Texas**
Philadelphia Alliance Regional **Apollo at Temple University**	**March 11 – 13, 1999** **Philadelphia, Pennsylvania**
UTC New England Regional **Meadows Music Theater**	**March 18 – 20, 1999** **Hartford, Connecticut**
Johnson & Johnson Mid-Atlantic Regional **Rutgers University**	**March 18 – 20, 1999** **New Brunswick, New Jersey**
Great Lakes Regional **Eastern Michigan University**	**March 25 – 27, 1999** **Ypsilanti, Michigan**
National Championship **EPCOT Center, Walt Disney World**	**April 22 – 24, 1999** **Orlando, Florida**

Popular Micromouse Algorithms, Part III

The Flood-Fill Algorithm

by Tak Auyeung, PhD
University of California, Davis



This is the third in a series of articles that discuss various algorithms ("algorithm" is a fancy term for "method") used by micromouse robots to solve the micromouse maze in competition. IEEE chapters have organized these annual competitions all over the U.S. and they have enjoyed a steadily rising popularity. Remember, while the exact rules differ among the competitions, depending on the intended contestants, the main objective remains the same: use a robotic "mouse" *to solve the maze as quickly as possible*. The basic premise of the problem is that the micromouse robot does not know the configuration of the maze before its first run in the maze. The coordinates of the destination, on the other hand, are known. The robot is allowed to store information and repeat solving the maze within a time limit.

Most micromouse robots can only sense whether there is a wall directly ahead, to the left and to the right. Based on such limited information, the robot must rely on proven algorithms to systematically explore the maze to find a path to the destination. A smart robot even tries to find the shortest path to the destination to minimize the time it takes to travel there. In previous issues, we discussed the Wall Hugging and Depth-first Search algorithms. In the July 1998 issue, we employed the Wall Hugging algorithm and discovered its main fault. In essence, if the robot swims along the shoreline of a lake, it will never reach an island in the middle. Therefore, if the island is its destination, it will fail. The failure is, of course, attributable to the inadequate algorithm. In the November issue, we discussed another popular algorithm used to solve the micromouse maze, the Depth-first Search (DFS). The main advantage of the DFS is that it guarantees that the robot will explore all cells that can be reached from its starting cell, and map them. Unfortunately, DFS does not provide the shortest path to the destination, a necessity for accomplishing the objective of the competition — *to solve the maze as quickly as possible*. At this point, you may want to review some basic information provided in the first article. If so, see the sidebar on page 46.

A Flood-Fill Algorithm

A faster, less intuitive method is a little more complicated than the wall hugging and DFS techniques, but has the advantage of finding the destination without having to explore the entire maze. That method is the subject of this article – the Flood-fill algorithm. This method works *only* for mazes that have known coordinate-designated destination cells. The principle of the flood-fill method is to give each cell the most optimistic estimate of cell distance from the destination (i.e., as if the maze has no walls). For instance, if the maze is 3 x 3 cells square, and the destination is the middle cell, the most optimistic estimated distance from each cell to the destination, assuming the robot cannot move diagonally, is as follows:

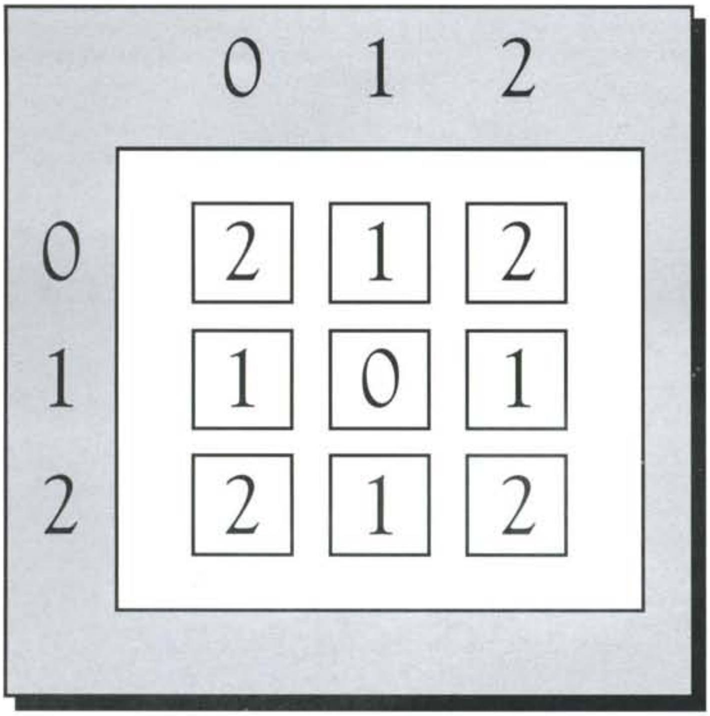


Figure 1.
Flood-fill maze setup

The key to the flood-fill method is to update the most optimistic estimated distances, and therefore the value of the cells, as walls are discovered. *The robot always moves to the open neighboring cell with the lowest distance value.*

An example

Let us go through an exercise with a real maze (note the walls in Figure 2) before the method is presented in pseudocode. We will now solve the following maze (with values initialized for each cell):

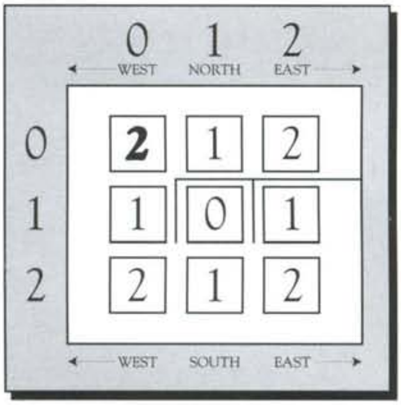


Figure 2.
Robot starts at cell [0,0]

The cell with a boldface number indicates the starting location of the robot, in this case [0,0] with a value of 2. Based on the value of the cells, the robot at cell [0,0] should either move to the east or move to the south (move to a cell with a lower value). Let us assume that the robot moves to the east.

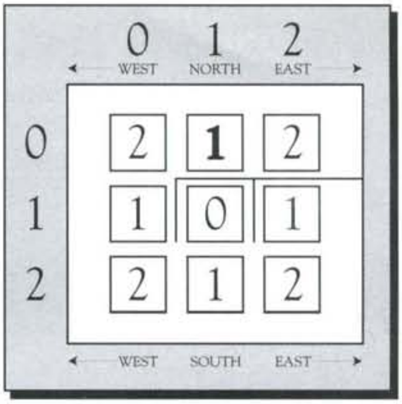


Figure 3.
Robot at cell [0,1]

At this point, both open neighboring cells have values higher than the current cell. This condition is only possible if the current cell is the destination, with a value of zero. *Not being at the destination and having no open neighboring cell with a lower value is a condition that necessitates updates!* How should the values be updated?

Let us, for a moment, trust the values of the neighboring cells. If the true distance from cell [0,0] to the destination is **2**, and so is the distance from cell [0,2], the most optimistic distance from cell [0,1] is **3**. In fact, as a rule (let's call it *the global consistency rule of flood-fill*), the following applies: *if a cell is not the destination, its value should be one plus the minimum value of its open neighbors.* Remember that this rule applies **globally**, i.e. not just to the presently occupied cell but to all cells that have been explored. Therefore, we update the value at cell [0,1] to **3**.

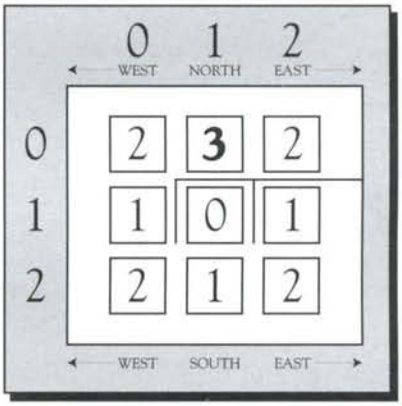


Figure 4.
Robot at Cell [0,1] - The Global Consistency Rule of Flood-Fill

The curious reader will now ask, how about cell [0,2]? Cell [0,1] is the only open neighbor of cell [0,2], should the value of cell [0,2] be invalidated? The robot, unlike the reader, cannot see the entire floor plan of the maze. When the robot is at cell [0,1], it does not know about the wall between cell [0,2] and cell [1,2]. Therefore, as far as the robot is concerned, cell [0,2] and cell [1,2] are open neighbors, and their values are still valid.

Now the robot again chooses to move to an open neighboring cell with the minimum value. Since cell [0,0] and [0,2] both have the minimum value of **2**, we arbitrarily move to cell [0,2].

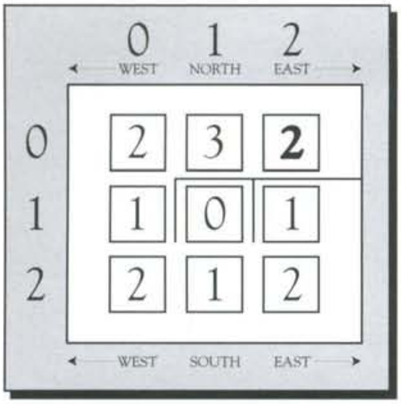


Figure 5. Robot at Cell [0,2] - Update Required.

At this point, the robot realizes that cell [0,2] is a dead-end. Cell [0,1] is the only open neighbor of cell [0,2]. Obviously, the value of cell [0,2] violates the global consistency rule of flood-fill. According to our rule, the value of cell [0,2] should be updated to **4**.

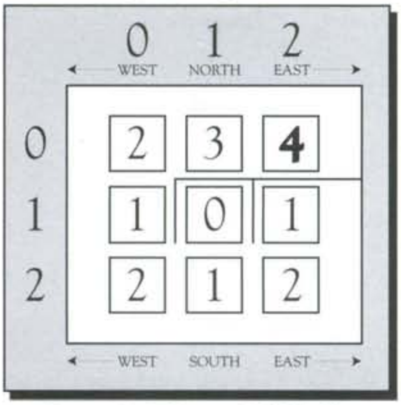


Figure 6. Robot at Cell [0,2] - Update Made.

Having reached the end of row [0], and finding itself boxed-in, the robot has only one place to go. The robot must move back to cell [0,1].

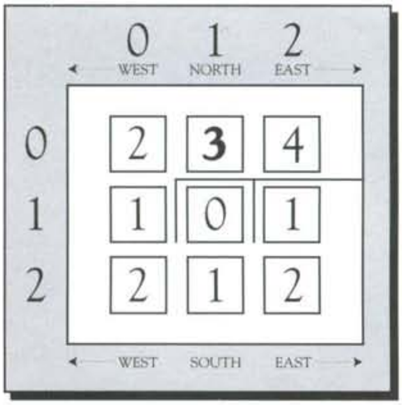


Figure 7. Robot Moves Back to Cell [0,1] - No Update Required.

Following the rule of moving to the lowest valued neighbor, and prevented from moving south by the wall, the robot again must move back and finds itself at cell [0,0].

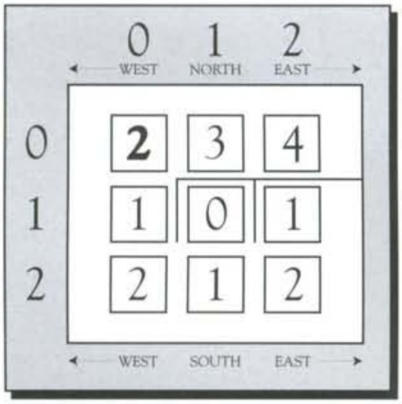


Figure 8. Robot at Cell [0,0] - No Update Required.

Not required to update any values by the *global consistency rule*, having explored cells [0,1] and [0,2], and following the *move to lowest value neighbor rule*, the robot must move to cell [1,0].

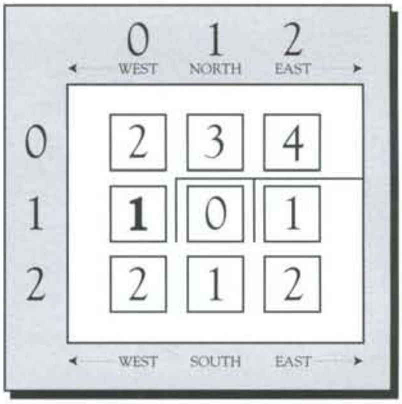


Figure 9. Robot at Cell [1,0] - Update Required.

The value of cell [1,0] violates the global consistency rule of flood-fill. This is because at this point, the robot senses the partition between cell [1,0] and cell [1,1]. Let us update the value of cell [1,0] so the rule is not violated; thus, we assign a value of **3**.

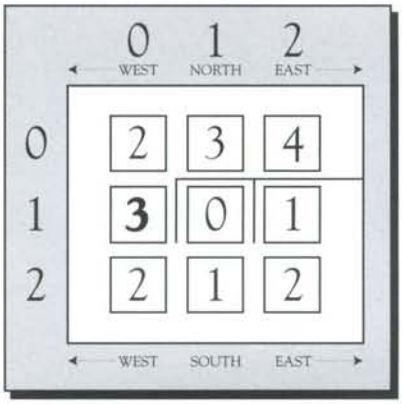


Figure 10. Robot at Cell [1,0] - Update Made.

The value of cell [1,0] is okay now. However, this update makes the value of cell [0,0] violate the global consistency rule that applies not just to the currently occupied cell but to *all* cells that have been explored. Let's fix that. The assigned value of cell [0,0] will be raised to **4.**

Moving on with assigning values according to the global consistency rule, cell [0,1] will now be given the value of **5.**

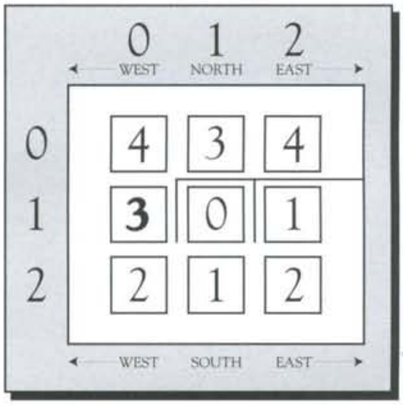


Figure 11. Robot at Cell [1,0] - Update Made.

Our algorithm can not stop here. Cell [0,2] must also be updated to the value of **6.** Hopefully, this is the last update.

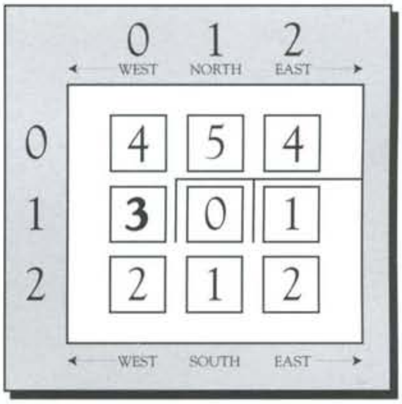


Figure 12. Robot at Cell [1,0] - Additional Update Required to Cell [0,2].

This time, the values of

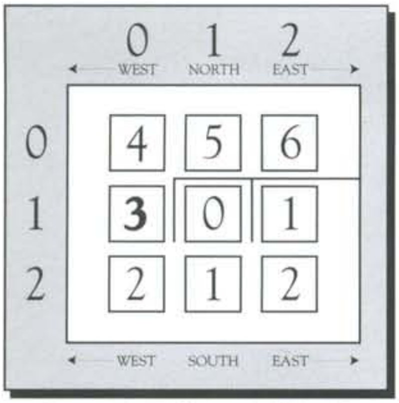


Figure 13. Robot at Cell [1,0] - Update Made to Cell [0,2].

all cells obey the global consistency rule. As the robot follows the rule *"move to the open neighboring cell with the least value,"* it moves to cell [2,0], then cell [2,1] and finally cell [1,1]. There are no further updates to the values of the cells.

The method

After walking through this example, we can now write in pseudocode the general method to perform a flood-fill exploration:

```
flood-fill
   let X = S the starting cell
   while X is not the destination
      update values starting with X
      select open neighbor N of X with
       the least value
      move the robot to N
      X = N
   end while
end flood-fill
```

This method is deceptively simple. It does not exactly describe how to update the values according to the global consistency rule. Let us make a first attempt to describe how to update the values of the cells:

```
update values starting with X
  repeat
    updated = false
    for each cell C in the maze do
      if value of C violates the
       global consistency rule then
          updated = true
          update value of C
      end if
    end for
  until not updated
end update values starting with X
```

This method will work, but clumsily so. If cell X is not a neighbor of cell Y, the value of X is never directly affected by the change of the value of Y. In fact, we can only check a subset of all the cells for violation of the global consistency rule. Let us make the method work more efficiently:

```
update values starting with X
  empty the stack
  push X on the stack
  repeat
    pop C from the stack
    if value of C violates the global
     consistency rule then
      update value of C
      push all open neighbors of
       c on the stack
    end if
  until the stack is empty
end update values starting with X
```

TERMINOLOGY

Maze board - a square board with regularly spaced pegs. In the Micromouse competitions, the pegs are 18 cm apart vertically and horizontally on the maze board, center-to-center.

Partition - a piece of "wall" that fits between two pegs. In the Micromouse competitions, the partitions are 5 cm high.

Cell - a square formed by pegs at the corners. We will use the convention that the cell at the upper left corner is cell [0,0]. The cells are numbered sequentially as follows: Keep in mind that the row designator is stated first and then the column. Thus, cell [0,0] is the northwestern most cell, progressing east the next cell (using the first number of the cell identifier as the horizontal or row designator) is then [0,1] followed by [0,2], etc. Using this convention, and moving south from cell [0,0], the next cell is [1,0]. Thus sequentially south in the first column we start with [0,0] progressing to [1,0], [2,0], [3,0], etc., for however large the maze may be.

Start location - cell [0,0].

Destination - Some locations with known coordinates that the mouse needs to go to. In the Micromouse competitions, the destinations are cells [7,7], [7,8], [8,7] and [8,8]. If the robot reaches any of these cells, it has solved the maze.

Reachable - If cell B is reachable from cell A, there is a path from cell A to cell B (and vice versa).

Neighbors - For cell [x,y], the cells [x+1,y], [x-1,y], [x,y+1] and [x,y-1] are the neighbors.

Open Neighbor - If cells A and B are open neighbors, there is no partition between them. Open neighbors are automatically reachable.

Basic Robot Abilities

The physical design of a robot can affect what the robot can do. However, since our focus is the method to solve the maze, let us assume minimal features from the robot. Regardless of design of the robot, let us assume the robot has the following basic abilities:

Turn 90 degrees clockwise and counter-clockwise.

Go forward one cell and stop.

Sense a wall in front of the robot.

Sense walls to the right and to the left of the mouse.

Once a wall is sensed, remember the wall in internal memory (i.e., build a map).

Keep track of the current coordinate.

Knows if the robot is at the destination.

This method uses a stack to keep track of cells whose value may violate the global consistency rule. Cells that may violate the rule must be open neighbors of a cell whose value is just updated. This is exactly why the method pushes all open neighbors of a violating/updated cell on the stack. These possibly affected cells will eventually be popped from the stack and be checked against the global consistency rule.

Note that the flood-fill algorithm can be reapplied when the mouse is at the destination [1,1] in the example. This time, cell [0,0] is the new destination, having a value of 0. The algorithm then tries to move the mouse from [1,1] to [0,0]. Note that this "reverse path" can be different from the "forward path" from [0,0] to [1,1].

While several organizations conduct micromouse maze competitions and the rules and criteria vary, the one apparent universal constant is to get from start to destination in the shortest possible time. From the example, you already know that the flood-fill method does not necessarily explore all the cells in the maze. This fact is important because it implies the partial map built from flood-fill exploration is not sufficient for finding the shortest path from the starting cell to the destination cell. Better algorithmic solutions for mapping the maze are in the development phases and may satisfy our "need for speed."

In this and previous articles we have explained some methods that explore the maze and find the destination. As far as the maze is concerned, it is solved. However, the micromouse contest is *not just* about solving the maze, *but solving it in the least amount of time*. Given two robots that can move at the same speed, the one that takes a shorter path will yield a shorter run time. It is, therefore, important to find the *shortest* path from the starting state (i.e., the starting cell *and* the initial direction) to the destination cell. In the next article in this series on algorithms we will explore a method of finding the shortest, and thus the fastest, path from the starting position to the destination cell, the A* algorithm.

RS&T

*We met **Tak Auyeung** at the IEEE Region 6 micromouse competition at UCD, where Tak teaches the UCD Micromouse Lab. In his other life, he's the software development group leader for embedded controllers at Zworld.*

The Trouble with Technology is due to both ignorance and expertise. It's easy to understand how inexperience and ignorance lead to unwise use of new science, but let's also consider the creative play of genius. Expect "rackers" will do with robotics what hackers have done with software.

So Robotic Burglars are Inevitable. Britain's *New Scientist* reported that 3Com's new palmtop PC can be programmed to capture infrared car lock codes. Currently, code capturing usually requires the interception equipment to be operated by humans. But hidden, low-profile mobile robots could make crime-by-proxy much more common.

If You Liked the Mechanized Violence of your army days, then you might love the pounding, screeching and smoke of robot warriors bashing each other by remote control. Imagine an arena filled with a thousand roaring fanatics, on their feet, cheering, raging and booing more intensely than soccer fans.

> **"I love the smell of burning robots in the morning"**
> **—Bob Bickford**

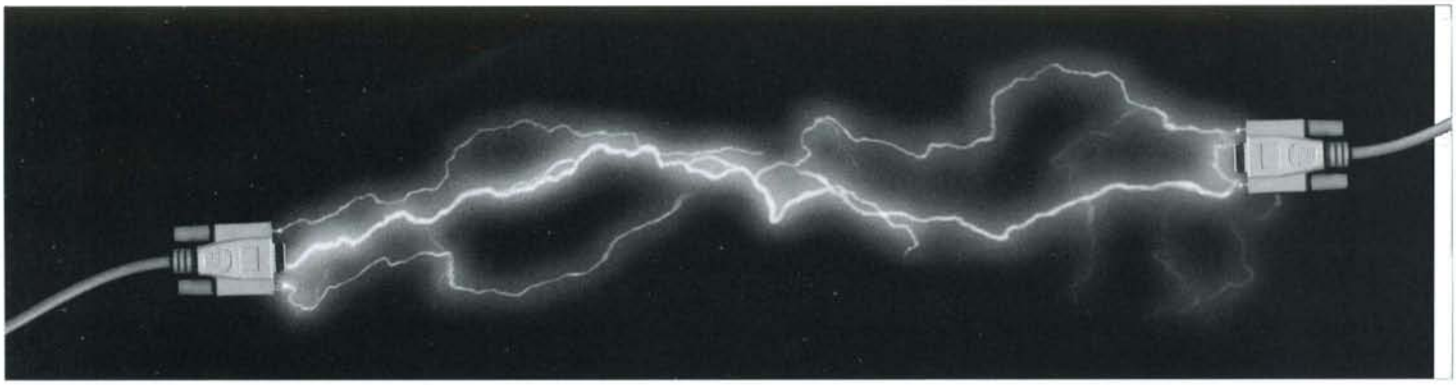
Unfortunately, you may have to do just that: imagine it. If you missed the last four years' annual *Robot Wars*, you may have missed a piece of robotic history. The games that some call the "monster truck rally of robotics" have been broiling in court proceedings since before the 1997 event. A scheduled 98 event was cancelled. Then, an alternative event, Robotica, a grass-roots effort heavily supported by the competitors themselves, was cancelled by a last-minute legal threat in August.

The whole debacle angered hundreds of competitors. Many of them had invested several months and thousands of dollars in their *robot-a-robot* fighting machines. A few managed to use their machines (but not their non-refundable airline tickets) at other events around the U.S. during September.

So imagine how readers of the techno-culture *Wired* magazine felt when *Wired* ran a major photo feature on Robot Wars, which boldly announced the 1998 schedule *after it had been cancelled months earlier.* A couple of teams (and a news camera crew) actually showed up for the cancelled Robot Wars event.

The Battle over Robot Wars continues to raise real casualties. As you can imagine, many of the most active supporters of Robot Wars are afraid of being sued by Robot Wars LLC. In this case, protecting the trademark threatens to destroy the whole venture.

This whole thing is somewhat understandable. Besides the fun and the creative outlet (the desire to satisfy robotic urges) there are investments to consider. A British film company, Mentorn, which runs a game-show version of the event in England on the telly, expressed interest in filming a US-based event. Then of course there are potentially lucrative "ancillary" benefits (like the licensing rights for toys and other merchandise) if and when Robot Wars becomes well-known.



Steve Plotnicki of Profile Records, who owns half of the venture, says he wants everyone to enjoy competing, and acknowledges that robot warriors will certainly compete on their own, staging events on their own without the involvement of the LLC. But can competitors call it "robot wars" without being sued? "We can't stop people from speaking about Robot Wars, but we would stop people from commercial use of the name."

For the latest scoop, perspective warriors should visit www.customforum.com/robotwars/, where veteran competitor Carlo Bertocchini hosts an unofficial yet better-than-official forum for warriors.

To taste the 96 and 97 events through RS&T's exclusive photos and narratives (and gain tips on winning), start at RS&T's website, www.RobotMag.com, and browse to "Compete, Win, Destroy."

Perhaps the most complete web site is run by robot warrior Andrew Lindsey at www.cybercomm.net/~alindsey/. Drew has an encyclopedic collection of hundreds of excellent photos there.

RS&T will continue to detail how to construct your own destructo-bots, since almost all the resulting robots can be used in other competitions, and all of the work is fun and educational.

Robot Wars is a trademark of Robot Wars, LLC., Robotica is a trademark of ClineWorks.

Western Canadian Robot Games Winners to receive new or renewed subscriptions as part of their prizes. Congrats to Mike Alexander, John Spearham, Jason McKay, Chris Johnson, and Mark Single. Thanks to Mark Hillier and Craig Maynard for inviting RS&T to the games for the second year in a row.

SUBSCRIPTIONS & RENEWALS

CHARTER SUBSCRIBERS paid by January 15th, 1999 may extend their subscriptions by:

- Converting from 6 to 12 issues by sending a check for $19. This option will extend your subscription to a total of 12 issues.
- Renewing during January and February, 1999 for a special charter renewal rate of $34. This option will add 12 issues to your current 6-issue plan for a total of 18 issues.
- Canadian Charter Subscribers. Renew prepaid during January, 1999 for 12 more issues for only $49 US.
- Don't miss a single issue! Send a check or money order to arrive by January 15, 1999. Mail to: Accounting, *Robot Science & Technology*, 2351 Sunset Boulevard #170-253, Rocklin CA 95765.

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- Most of the cost of international subscriptions is for shipping.

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Index

Feedback Loop

Casting Around for Ideas... and We Have a Winner!

I enjoy your magazine a lot...keep up the good work. I do wish it would come on a steadier basis, and by that I mean monthly...for real. I know you are new so I understand.

I have a comment about your fabrication series in general, and particularly the plastic casting articles. They are very good and very well thought out, but in my fabrication of robots I come across a lot of plastic parts that I need to create. But I don't have a model to go by, and when you create a robot from scratch, sometimes you require parts that don't exist and there is nothing to use for making a mold. I was wondering if you could someday cover this topic. I thank you very much, and can hardly wait for your next issue.

— Jose Moreno

Dear Jose,

Thanks for your encouragement, understanding and patience. As you mentioned, we are new, and experiencing the ups and downs that are common to all startups. We have several goals, and the primary one is to publish as good a magazine as we can. Secondarily, we are working toward publishing monthly, on time, every time. We believe we are near the mark with the desired quality, and we have added staff so that we can process material faster, making the second goal achievable soon.

Your comments on the fabrication series are timely, and you have probably already seen Flint Mitchell's article on vacuforming plastic (pages 20-24) in this issue. The series will continue, and we are now processing two new articles. One will be a how-to feature on creating finely detailed rubber skin for your robot. The other will feature a full up, hands on construction, from soup to nuts, of a commercially available robot kit. More to come so stay tuned.

It's a Wonderful Art Form for Shared Experience

I am glad that you are starting to send it in an envelope.

I know that you have to balance articles, but could you have a short article describing a robot, what it is, what it does, and how it works, etc.

Sometimes you can get a lot of ideas for your own robots just by reading and seeing how somebody else did something.

— Allen Mosley

Dear Allen,

We value your comments on the use of envelopes, and you put your finger right on the main purpose, to keep that baby as clean as it was when it left the factory.

The kind of hands-on, been-there articles you like will continue to be published in RS&T. In fact, the next issue will include a feature by Ronni Katz in which she describes the engineering and construction of her robot warrior ***Chew Toy II****. It includes insider stuff that only a veteran bot builder like Ronni can provide. Keep in touch, Allen.*

Site Under Construction

I got the third issue from my mailbox yesterday, breathed a sigh of relief, wrung out my sweat-drenched shirt, and began bandaging my chewed fingertips (just kidding!). Seriously though, the suspense was becoming unbearable.

By the way, the third issue is GREAT! The improved format is wonderful, and the reference sections are really nice. Keep up the great work. I'm looking forward to reading more about AI software techniques and fuzzy logic in upcoming issues.

— John, a relieved subscriber

Dear John,

We know that absence does not necessarily make the heart grow fonder, but we hope number three was worth the wait. As we mentioned in answering Jose Moreno's kind letter, excellence and growth come at a price, and that price has been paid in time. We are determined to be a monthly magazine as soon as possible.

You will obviously enjoy Professor Mohammed Jamshidi's feature article on Intelligent Evolving Soccer Robots (Part II) in the next issue of RS&T. Aided by his trusty companions Denise Padilla and Marco de Oliveira, he will provide the final installment of the discussion on soft computing that commenced in our November issue.

Now, if He Just Had a Robot Cat! (Next Project)

I just got hooked on robotics this year. I picked up the premier issue of *Robot Science & Technology* at this year's Trinity Fire-Fighting Robot Contest. Since then, I have made a few robots, one of which is a six-legged walker that shoots toy darts at the cat. I just want to say that, as a beginner, I find your magazine most informative and a joy to read. However, I don't think the cat cared for the *Basics of a Digital Brain* series and the article about pyroelectric detectors. Without those articles, I would still be scratching my head, trying to figure out the 68HC11 and the pyroelectric detector.

I look forward to the next issue.

— Jason Boxall

Dear Jason,

Thanks, and what you have picked up on is our desire to provide roboticists with information they can really use. We are glad to have been of assistance, and hope the cat never figures out how you got to be so smart so fast. No self-respecting publication wants to find itself wrapped around a fish or on the bottom of a birdcage, but the worst fate of all is to be used for kitty litter.

Another Way to Skin a Servo

Many thanks for a great publication. I have extended my subscription for an additional twelve issues.

I was especially interested in November's article by Karl Lunt on modifying servos to get continuous rotation. I followed steps 1-5, then, instead of removing the potentiometer, I removed the link that locks the pot to the output shaft/gear. Then I added a thin layer of grease to the bronze bearing around the shaft.

Keep up the great work. I am looking forward to the next issue.

— Ralph Folsom

Dear Ralph,

It seems that everyone has a different formula for modifying servos. The method we detailed in November replaces the potentiometer with twin fixed resistors, dividing the resistance equally, keeping the servo centered. Be sure to measure the resistors to ensure they are truly of equal value. This alternative removes the need to find exact center with your eyeball, and enhances reliability by removing the pot (pots get electrically 'noisy' as they age). Another improvement would involve replacing the pot with a higher-quality component that requires 10 or more turns from min to max. This technique improves precision, but of course, the accuracy of both resistors and potentiometers can fluctuate with large temperature changes (keep an eye on cooling when building your bots).

Other methods use programming commands to continuously re-center the servo. But this presents a problem often overlooked in our Digital Age: a digital command might never really find the exact analog center, causing the servomotor to vibrate. As you can see, all methods have pros and cons.

Thanks for your excellent letter, giving us another opportunity to exchange robot building ideas. Thanks for your renewal.

RS&T

Submission Guide

You Can Write For Robot Science & Technology

RS&T accepts quality feature articles from individuals, and our rules which govern acceptance of manuscripts are tight but fair. If you would like to write for us, just follow the guidelines provided here, and submit the manuscript to us. If your article meets our requirements, we will work with you, and the result could be an article in our magazine. You should:

Tailor your presentation. About half our subscribers are engineers and academicians, and most of the rest are students, so the presentation can range from intellectually stimulating for the most technically adept, to understandable for those who are not yet at the highest level. All who read our magazine are curious about all aspects of technology within the exciting science of robotics. They are interested in how things work, and ultimately might like to get involved at a hands-on level. Our desire is to provide something interesting and challenging for everyone.

Educate and inform. We want cutting-edge articles. We welcome articles on hardware or software, and those that concern microprocessors and programming robots with readily available computers, programs and materials. If your article is theoretical, you should lead every major idea in an intellectual way, but spend some time to explain what that idea means in an instructional manner, like a tutorial.

Be Original. It is important that you be the author of your article and the purveyor of your ideas. We will evaluate previously published material on disciplines related to robotics, like artificial intelligence, if the material has been extensively revised and made applicable to robotics through an original thought process. Our subscribers want to read about new technology, fresh ideas and new approaches to problem-solving.

Content

Short articles may contain 800 to about 3000 words, with the typical **feature** manuscript for RS&T containing 3000-3500 words, and several photographs, figures, graphs or tables. Be clear, concise, and accurate.

A general outline:

Introduction. This is your opportunity to acquaint the reader with your subject matter with general information. It is the roadmap for the discussion that follows.

Discussion. This is a detailed discussion of your subject matter, and it should unfold in a logical, ordered manner. Check all material presented as facts.

Conclusion. This does not necessarily have to be a review of the article, but it does need to summarize it in general terms. It can also be used as a springboard to the next segment if the article is one of a series.

Details for text

The first page should include your name, address, telephone number(s), e-mail address, website URL and date.

We prefer that submissions be attached to e-mail as MS Word (PC or Mac) or WordPerfect files. If you do not have those programs, submit the article in ASCII, MS-DOS text, or rtf. Do not embed graphics, but send them in separate e-mails, to keep file size small.

If text is submitted in hardcopy, it should be on white, 8.5 x 11-inch paper, one side only, double-spaced in minimum 11-point type, and you should also provide it on a 3.5-inch floppy disk in the programs listed above.

Use short, crisp sentences and keep paragraphs to about three or four sentences. Use subheadings to break the text into easily readable and identifiable sections.

Verify the spelling of names, titles, and company names and that dates, phone numbers, and references are correct.

If you use acronyms, the first reference should be fully described, followed by the acronym.

Be sure to refer to all photographs, figures, tables and lists.

If you are writing a construction article, you should provide the reader with the following information:

- Parts list.
- Known sources for obtaining parts. Include the complete address, phone number, website URL and e-mail address.
- Any special equipment needed for construction or testing.

Photographs

Four to six photos are desired for each article submitted. Do not send negatives.

We prefer to scan photographs ourselves, and 4 x 6 or larger glossy color prints give us the most latitude. Electronic submission of photographs is not acceptable.

Keep the background neutral.

Focus, depth of field and detail are vital. Do not send photographs that are out of focus. Automatic focus cameras often produce fuzzy images.

Include the whole subject in the photograph.

If you are photographing a robot, we must see the whole figure, but we also want close-ups of the drive train, power plant, sensor array, or anything else that is captivating about your robot. If your article is a how-to piece, ensure that pictures of each phase of your project fit with the text.

Caption each photograph. Nobody knows better than you what you have photographed, so number each one on the back with a sticker to preclude scoring the photo. Reference them on a caption page enclosed with your story.

Other Graphics

All graphics must be 300 dpi, and a minimum of 2-inches square. We may redraw figures to maintain consistency among articles. Do not place graphics into a word processing document. Save them as separate files in the following formats (Mac or PC):

- **Schematics**—TIFF, EPS or BMP files.
- **Line art**—Adobe Illustrator, EPS, TIFF, or BMP.

Editorial Process

All material accepted for publication will be subject to editing by our staff. If your manuscript contains a large amount of misspellings, grammatical errors, or requires extensive editing for any other reason, it may be rejected. Do not rely solely on a spell-checker.

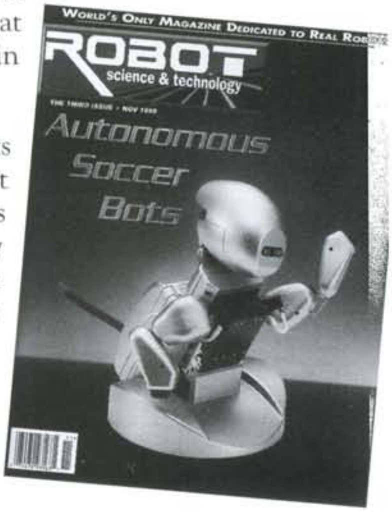
During the editing process, we may request clarification or additional material. Your responses should be as prompt as possible, and we would appreciate a twenty-four hour turnaround. Often, telephonic communication elicits additional information, so please be accessible.

The initial layout is proofread during staff review and by you. Again, a quick turnaround will be requested. Basically, you check for content, and we design the article.

Miscellaneous

Provide a brief background sketch, including (but not limited to) where you work, your education and e-mail address if you wish to be accessible to our readers. We encourage reader comments and responses to all articles.

Figures, listings, tables, and captions should be provided at the end of the article, or in separate files.



We will accept manuscripts for review, but they will not be returned unless a SASE is provided. Article ideas may be approved in advance, but no guarantee of acceptance is given until the final copy is reviewed.

All artwork must be submitted with the feature article.

Send submissions to:

editor@robotmag.com

Mail hard copy and graphics to:

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USA

RS&T

On the Societal Impacts of Robotics

Dear RS&T,

My 13-year-old son is doing a history fair paper on the present and future impact of robots on society. He would like to refer to your articles on *Autonomous Mine Clearing Robots* and *Atlanta Bomb Squad Talks about Bots*, but he's allowed to reference only one Internet source. Did these or similar articles appear in your magazine? If so, what issue and page number?

— *Jane McAshan*

Dear Jane,

RS&T first featured anti-bomb robots on our website during the 1996 Olympics, and we've stayed in touch with the technology ever since. For a single Internet source on all facets of robotics, I would recommend our own www.RobotMag.com.

For a quick fix, read Prof. Robin Murphy's article, describing Colorado School of Mines' rescue-research robots Silver Bullet and Bujold, on page 34 of our Premier Issue. In addition, July's page 38 shows NASA's hazardous duty robot, Andros, performing for tourists at EPCOT. A librarian can find an article on Army training with Andros (built by Remotec), in an old issue of *Soldier* magazine.

RS&T follows robotic sports, an area which researchers find useful for examining adversarial relationships. Prof. Manuela Veloso at Carnegie Mellon University programmed Sony's autonomous four-legged RoboPets to play soccer with a golf ball. (See RS&T, Volume 1, Issue 3, page 28.) Honda's 6-foot bipedal humanoid model P3 robot negotiates stairs and aisles, and was configured to play two-legged, life-sized soccer for July's RoboCup, held in conjunction with the human World Cup of Soccer in Paris. (See RS&T's Premier, Vol. 1, Issue 1, centerfold.)

For commentary on other effects of robotics in society, see K. E. Drexler's book, *The Coming Era of Nanotechnology*, and James Hogan's *Mind Matters*, about the impact of Artificial Intelligence (AI).

Your son's paper broaches a subject loaded with important concerns, because robots will continue to impact society immeasurably. The nuclear accidents at Three Mile Island and Chernobyl showed the world that **there are some critical tasks, vital to our survival, which cannot be performed without robots.**

Other tasks are less dangerous but are certainly life-and-death serious: Several companies produce robots for ultra-precise surgery.

Manufacturers are not the only players, or necessarily the most important. It's my opinion that "amateurs" are effecting change as much as the Big Boys. Each year, thousands "play" with robots simple and complex in mock battles and competitions. Looking to the future, I think it's fair to predict that even **big-money sports will be dominated by mega-machines** of superior intelligence. Consequently, robotics will radically change TV, advertising, and then our culture as a whole.

This day may not be far off. Several authorities, including Prof. Kevin Warwick at Britain's U of Reading, posit that AI systems will become more intelligent than humans. They'd also be more reliable, and faster. In his non-fiction thriller, *March of the Machines*, it would be natural for the machines to treat humans much as we treat animals. Think about that.

Does this scenario seem unimaginable? Prof. Rodney Brooks, leader of the prestigious Artificial Intelligence Lab at MIT, assured me that the **takeover of the robots** would not occur for probably 50 years!

Would it be so bad? Will humans fight technological change? Brooks pointed out that a denizen of the 18th century would never imagine electric lights, and might curse the invention as the work of the devil. Still, mankind evolves, society's values change, and subsequent generations will not view the world of the future with today's eyes.

Few people realize it, but intelligent, mobile, autonomous and powerful robots are here NOW. We must learn to accept them. We must gain hands-on experience with the technology. We must become **friends with our robots.**

Let's hope this helps.
—Mike

RS&T

FIRST Robotics, continued from page 11

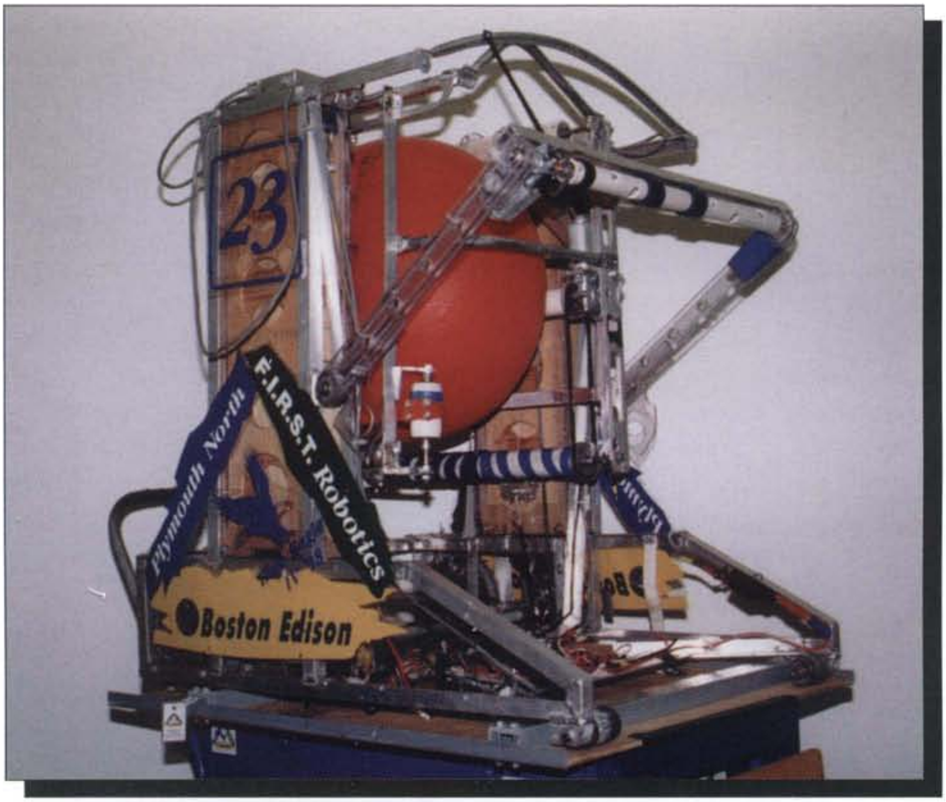
During the project, students observe firsthand the applied leadership, executive skills and methods required to manage successful organizations. One way to accelerate this learning experience is to place students in positions where they lead critical elements of the project, and this is often done. Basically, the most important attribute for team members is their ability to work with each other to complete group assignments to help the team and create a competitive robot. The size of the team, beyond the minimum core of professional adults and a group of interested students, does not matter.

Funding

Finance campaigns are as much a part of the tournament as the actual design and fabrication of the robot. Financial models used by FIRST teams vary as much as the makeup of the teams. Cost-sharing is a common attribute, and all participants, organizational and individual, contribute to the project's budget. For example, a corporation may fund the entrance fee, construction costs for the robot, and travel and lodging costs for their employees who act as mentors. The high school would be responsible for the travel and lodging costs of students and faculty sponsors. Many high schools solicit donations from local businesses and initiate other fundraising activities to pay expenses associated with FIRST competitions. Team budgets have ranged from $12,000 to about $80,000, with most of the expense in travel and lodging costs. Entrance fee and construction costs for the robot require an investment of about $10,000-$12,000.

Pre-Season

The FIRST competition does not begin until January, but many activities can start before the new rules are presented at the kick-off. These include organizing the team, identifying leaders, seeking sponsors, fundraising, studying past competition videos, and learning safety procedures.

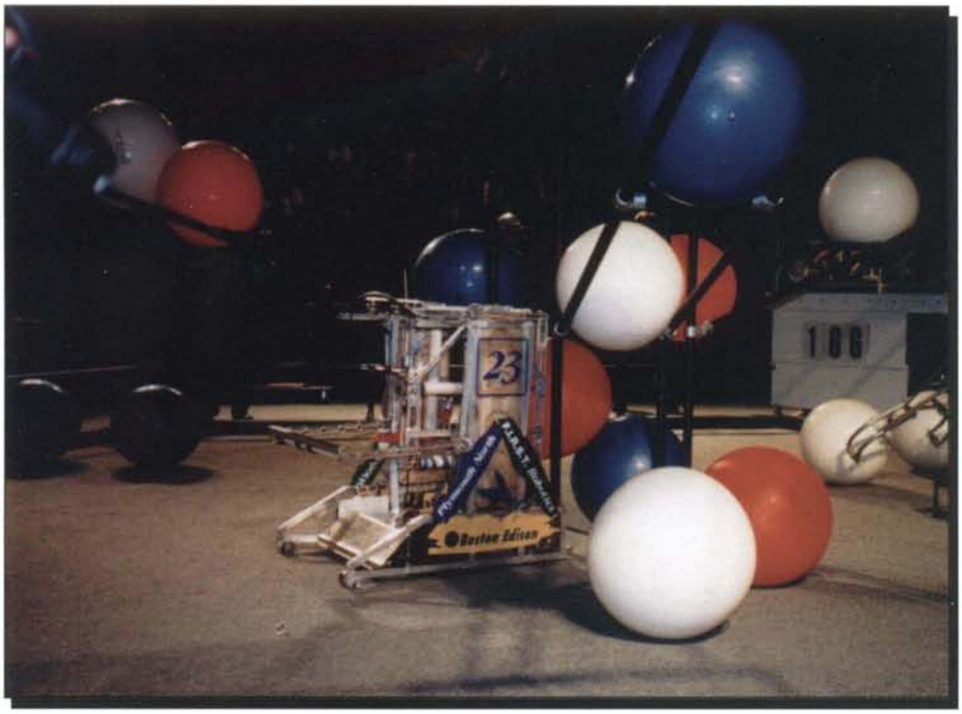


The PNTA robot "Blue Eagle IV," in crouched position.

Success Stories

The Plymouth North Technical Alliance (PNTA)

This is my team, and it was formed in early 1995 as a partnership of Plymouth North High School and Boston Edison Company's Pilgrim Station, a branch of the company's nuclear facility. When we participated for the first time that year, bright, ambitious students began signing up for the program because they viewed it as exciting, challenging and tailored to serve their interest in the application of math, science and technological principles. That year, we finished in the top 15% in the national competition and won rookie of the year honors at EPCOT. Since the team's creation it has grown from a handful of members to more than 50 students, over 100 total participants and it is sponsored by 120 businesses.



"Blue Eagle IV" in action at the central goal at EPCOT Center.

Today, we have permanent spaces assigned where a former vocational training facility once prepared students for uninspiring jobs. We operate after school, in the evening and on weekends and our students manage and utilize an impressive array of sophisticated technology. We engage young people in the process of learning and acquiring skills at a rate previously unimagined. The community of Plymouth has recognized the program as an effective, fertile environment for inspiring young people to acquire knowledge and skills, attributes that will place them in positions of leadership in the future. As a result, local support has been tremendous. For the 1998 competition, businesses and corporations demonstrated their support by making contributions to the team totaling about $40,000.

Lee Oliver, Senior Vice-President of the nuclear facility, our team's principal underwriter, said, "FIRST opens a pathway to creativity. It shows students and other participants that there are no boundaries on personal growth and achievement. That's why Pilgrim Station supports this initiative."

Former PNTA team members are continuing their education at Boston College, Boston University, Carnegie Mellon University, Duke University, Northeastern University, Worcester Polytechnic Institute, and Wheaton College. Institutions such as those are well aware of the important work that FIRST is doing. For example, Plymouth North graduate and PNTA FIRST team member Kesha Gianakos now attends Wheaton College. Her acceptance letter from Wheaton noted that, "Your superior achievements as part of the national robotics competition were particularly impressive to us in the admissions process." Kesha herself had this to say about the program, "I couldn't feel more prepared for college than I d right now with all of my experienc from this program. I know a lot mor than people who are entering the engineering field who haven't been in a mechanical environment like this. No only that, but I've learned how to lead respect, work and communicate wit people."

East Technical High School

The FIRST program has contribute significantly to a real success story, th salvation of East Technical Hig School, an inner city school in Cleveland, Ohio. Jerome Seppelt, FIRS Program Manager at the school said "Five years ago, East Technical Hig School was slated to close. Enrollmen was down, the daily absentee rate wa 34%, the school had a dropout rate o about 50% and only 43% had passed th state proficiency test. Then, in 1995 James Eaton, an engineer from NASA' Lewis Research Center introduced th FIRST program to the school. Chang was not immediately apparent, but soo NASA engineers and 15 students wer involved in building their competitiv robot. Not long after that, the FIRS robotic program became the extra-curricular activity of choice at the school In addition, other students began going to math and science classes on a regular basis. They had to find out wha was going on, and how the project wa progressing. Each day after school, th FIRST team would meet, divide int their sub-teams and work on the robot.'

Since 1995, a transformation has taken place at East Technical High School that is stunning. According to Jerome Seppelt, "The FIRST student engineering team now has 30 members, and more and more students are hitting the books to earn the 3.00 grade point average required to qualify for the team. Team members must apply for membership, and 30 are selected each year. The sense of anticipation is high for the 1999 competition, and we had 137 students apply for next year's team. In fact, the team's popularity has come to the point where more students try out for the FIRST team than for the football and basketball teams combined. Students are transferring to East Tech from all over Cleveland, and enrollment has grown from 900 at the inception of the program to 1400 at this time. In other developments, the school has become the science and engineering magnet school for the district, and the attendance rate is 82%, the highest average for schools in the district. The state proficiency test pass rate is now 71%. Twelve graduates of the FIRST engineering team are enrolled in four-year undergraduate engineering programs."

The program has flourished over the years, and during the 1996 FIRST tournament, the East Tech team finished ninth among the teams that competed. Success continued to follow the team. It captured the Xerox Creativity Award at the FIRST regional competition in Detroit earlier this year, and was a finalist for the Chairman's Award at the National Competition. The Xerox award is given to the team that displays the most creative design, use of components or the most creative or unique strategy of play. The Chairman's Award is presented to the team which is judged to have created the best partnership among the students, engineers and community. For this award, the judging panel reviews materials that consist of videos, photographs, or written accounts of team activities that are submitted prior to the national championships.

This year's activity for East Technical High School was capped by a win at the 1998 FIRST Capitol Hill Invitational, held at the U.S. House of Representatives in Washington, D.C. in June. The East Tech partnership for the invitational included the Lewis Research Center, TRW, Inc., Battelle Memorial Institute and The Illuminating Company. Eight teams were invited, and the "Scarabs" of East Tech won the competition with their robot "Scarabian Knight." Representative Louis Stokes (Dem.OH), actually controlled the robot during a practice run, and said: "I applaud the students who are partipating in the FIRST program. I take particular pride in saluting students from East Tech High School, which is located in my congressional district. Through the FIRST program, students in schools throughout the nation are discovering that science and math can be fun. Further, with skills gained from participating in this innovative program, they are taking an important step toward securing their future."

The Plymouth North Technical Alliance competed against the East Tech High Team at the invitational. We are proud of having beaten them in one round, and congratulate them for going on to win the overall event. They are a wonderful example of what is possible when the best minds of industry are teamed with the imaginations and persistence of our young people.

Members of the East Technical High School team celebrate their victory at the 1998 FIRST Capitol Hill Invitational Tournament. The team, from Cleveland, OH, won with their robot "Scarabian Knight." Photo courtesy Jerome Seppelt.

That is the purpose and the legacy of Dean Kamen, Woodie Flowers, and FIRST, to demonstrate to high school students that they can achieve anything if given the right tools. These tools include the knowledge, wisdom and the time of the scientists, engineers, teachers, professors and others who unselfishly support this very worthwhile program.

1999 Schedule

The Calendar of Events on page 41 of this issue of RS&T provides the 1999 schedule for FIRST tournament activities.

Foundation Leaders

Dean Kamen, founder of FIRST
Dean Kamen is president and owner of DEKA Research & Development, a Manchester, NH-based company. He is also Chairman of Teletrol Energy Systems, Inc. Kamen, an airplane and helicopter pilot, is former owner and chairman of the Enstrom Helicopter Corporation. In 1985 he established Science Enrichment Encounters (SEE), a hands-on science museum for children in Manchester, N.H. Five years later he founded FIRST to inspire young people, and demonstrate to them that the disciplines of science and technology are exciting, accessible and rewarding.

In 1995, Kamen earned the Hoover Medal for "innovative and imaginative leadership in awakening America to the excitement of technology and its surpassing importance in bettering the lot of mankind." The medal, established in 1929 and awarded annually, commemorates the civic and humanitarian achievements of former President of the United States Herbert Hoover, and is sponsored by five major engineering societies. In 1992 he received an honorary doctorate in science from Worcester Polytechnic Institute, Worcester, MA. In 1994, Kamen was named Engineer of the Year by Design News Magazine.

Woodie Flowers, PhD, national advisor to FIRST

Woodie Flowers is the Papallardo Professor of Mechanical Engineering at MIT. Each year, Dr. Flowers and Dean Kamen design the FIRST competition specifics. He also acts as the master of ceremonies at EPCOT. In addition to his duties as Director of MIT's New Products Program, he is a member of the Board of Directors of the General Scanning Corporation. He is also a member of the Board of Advisors of the Meitec U.S.-Japan Friendship Corporation, an overseer for Boston's Museum of Fine Arts and former host of the PBS television series Scientific American Frontiers. For his teaching, he has received the Goodwin Medal, The Baker Award, The Den Hartog Distinguished Educator Award from MIT, and The Western Electric Award from The American Society of Engineering Education.

Andrew M. Allen, President of the FIRST Foundation

Mr. Allen is a former NASA astronaut, a veteran of three space shuttle flights, who also served as a shuttle commander. A U.S. Marine Corps aviator, Allen was selected for the space program by NASA in June of 1987, and became an astronaut in 1988. Among his many assignments with the space agency, he served as Director of Space Station Requirements at NASA Headquarters.

Allen received his commission in the United States Marine Corps at Villanova University in 1977. Following graduation from flight school, he flew the F-4 *Phantom* from 1980 to 1983, and was later selected for transition to the F/A-18 *Hornet*. Mr. Allen participated in the introduction of the *Hornet* to the sea services, and also attended and graduated from the U.S. Marine Weapons and Tactics Instructor Course, and the Naval Fighter Weapons School (Top Gun). A 1987 graduate of the United States Navy Test Pilot School, he was a test pilot under instruction when selected for the astronaut program.

RS&T

If you have questions about the 1999 FIRST tournament, you can request information online or contact FIRST via mail, e-mail, phone or fax.

FIRST
200 Bedford Street
Manchester, NH
03101-1103

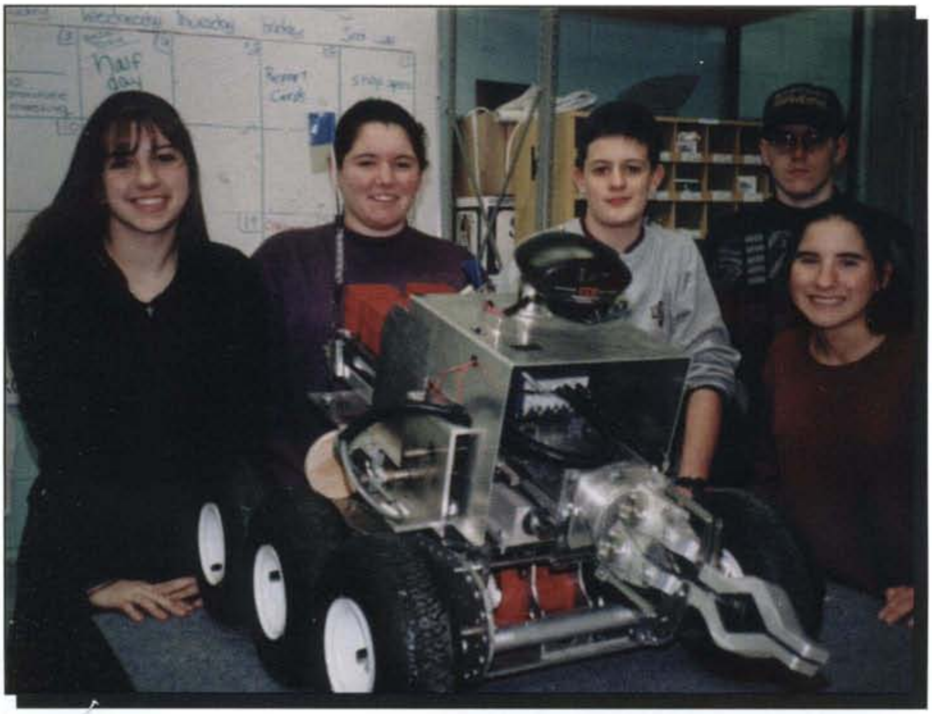
603-666-3906

800-871-8326

603-666-3907 (Fax)

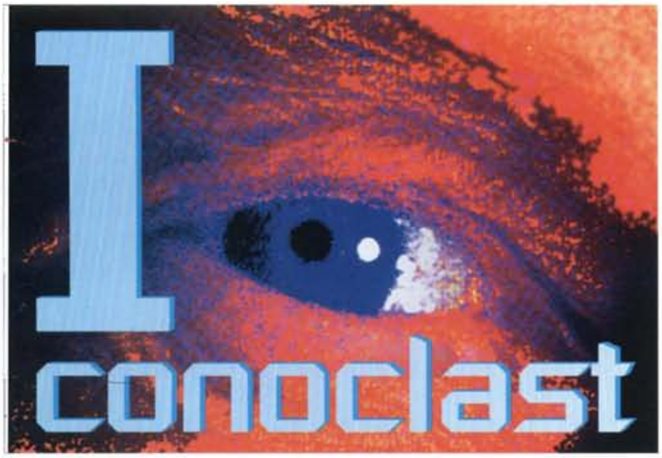
ddoiron@usfirst.org

www.usfirst.org



Plymouth North High School students (left to right); Abby Phillips, team rules compliance manager; Shannon Strassel, fabrication specialist; Chris Cotti, rover specialist; Brandon Gunn, electrical engineering and programming specialist, and Mellissa Roy, cost control manager, with "The Rover," PNTA FIRST team mascot. The robot is made from parts produced over the past five years of robot building at the school.

Michael Bastoni is a science and technology instructor at Plymouth North High School, Plymouth, MA. He is team advisor to the high school's FIRST robotics team. Mr. Bastoni has taught courses in power, energy, and transportation, pre-engineering and design, electricity/electronics, algebra, physical science, and engineering drawing. In 1994, Mr. Bastoni and Steve Verrochi, a mechanical engineer at Boston Edison's Pilgrim Nuclear Station founded the Plymouth North Technical Alliance. Over the past five years, the team's awards have included the following: The FIRST National Rookie All-Star Award, the Chrysler Team Spirit Award and the FIRST Chairman's Award.



JUST AMATEURS

Professionals can be hampered by vested interests, and sometimes it seems that only people who aren't professionals can pursue their own ideas.

I heard a most amazing and disappointing statement the other day. A well-known personage in the field of industrial robotics claimed that amateurs don't have the resources to make a contribution to robotics.

I should have asked "Joe" (I'll call the individual Joe to protect the guilty), "Joe, who do you think created the computer revolution? Who discovered the planets Uranus and Pluto? Who founded radio astronomy?" The answer is amateurs, that's who. These subjects, in technology and pure science, are only two of many with which I am familiar. Amateurs have made and continue to make significant contributions to other disciplines as well.

We are all familiar with how Steven Jobs and Steven Wozniak started Apple computer and the personal computer industry. They weren't trained in computer science, they weren't academics and they weren't in anyone's employ to design computers. They were college dropouts. Where were the big boys, the important professionals? Bill Gates, founder of Microsoft, was a college dropout also. What did these amateurs have that the professionals of the time did not? Vision. They were visionaries who saw beyond the narrowness of quarterly profits. Computers weren't only a potential business, they were cool stuff.

The early years of astronomy were also dominated by amateurs. The discoverer of the planet Uranus was a musician, and the discoverer of Pluto was an uneducated farm boy from Kansas. In 1881, E. E. Barnard, a photographer's assistant, discovered a comet. He went on to discover several more comets, photographed the Milky Way, and discovered the fifth moon of the planet Jupiter. What made these amateurs successful? Enthusiasm.

Why is it that Joe doesn't believe amateurs have anything to contribute to robotics? He says they don't have the resources. Which resources are they lacking? Big laboratories, machine shops, government grants, or a cadre of graduate students? That's true...but is it relevant?

Enthusiasm and vision lead to many innovations and unexpected discoveries. Where are the majority of mainline roboticists today? Some are in private business, some work for the government, especially in military applications, and many are in university laboratories. These researchers are doing fine work and their many accomplishments are published in journals, books, and on the web. While amateurs may not be able to do the same kind of work as professionals, they still have a lot to contribute. For one thing, amateurs have something that professionals do not have, and that is the freedom to pursue their own interests. People who work for companies can't do that. People who work for the government can't do it. And paradoxically, even researchers in universities can't do it. The advancement of research in universities is directly proportional to the amount of grant money the researcher attracts, which means catering to the wishes and desires of the granting agencies. It seems that only people who aren't professionals can pursue their own ideas.

What are amateurs anyway? The traditional definition is individuals or groups who are not paid to do the work they are engaged in. While amateurs may hold down "day jobs," that doesn't mean they can't, or won't, accomplish anything significant in robotics. After all, amateurs don't necessarily stay amateurs. Today, no one would call Jobs, Wozniak, or Gates, amateurs.

Unfortunately, Joe's attitude isn't unique or new. When E. E. Barnard was awarded the Gold Medal of the Royal Astronomical Society, the famous astronomer Simon Newcomb, recalling a meeting with Barnard many years earlier, said, "... I did not for a moment suppose that there was a reasonable probability of the young man's doing anything better than amusing himself." He later recognized his earlier misappraisal of a guy who was "just an amateur."

In 1919, Americans were devastated to learn that the World Series had been fixed. One of those who was blamed was "Shoeless" Joe Jackson, a left fielder for the Chicago White Sox. Jackson and other team members were banned from the sport for life. At a public press conference held during the time of the grand jury hearings, a little boy reportedly shouted out in a plaintive voice, "Say it ain't so, Joe!?

Amateurs can't contribute to robotics? Say it ain't so, Joe!

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Our multiprocessor architecture uses the latest in VLSI components and PC peripheral hardware. Professionally manufactured printed circuit boards connect to the GeckoBus™ architecture. GeckoBus™ minimizes points of failure and distributes processing across modules, and is designed to provide years of trouble free operation.

The CareBot™ is over four feet tall, with locomotion, power systems, and a GeckoFrame™ capable of transporting over 150 pounds. With USB internal cabling, high speed RF modems, and a scanning, high ping rate sonar, this upgradeable, expandable personal utility class robot already has third party developers lining up. The result? The personal robot you won't outgrow!

If the CareBot™ sounds versatile now, just wait. Coming soon are more application software, sensor, and positioning systems. Gecko Systems™ provides strong technical support, a 1 year warranty on all electronics (system intact[1]), 2 year warranty on the drive motors, and a 5 year warranty on the GeckoFrame™. Free, unlimited software upgrades for one year!

So, if you're ready to get the personal robot you've always wanted, get the one you won't outgrow. The CareBot™ can be yours for $2,395. Order yours from Gecko Systems, Inc., Suite 328, 402A West Taylor Avenue, Round Rock, TX 78664-4237 Phone: 512/868-9900 Fax: 512/868-1001. Visa, MasterCard, American Express, Discover, money orders, personal or cashier checks accepted. Monthly payments on approved credit. TX residents add 8.25% state sales tax. Allow 4-6 weeks for delivery. Shipping extra. Robot club member, educator, student, and third party developer discounts available. Dealer inquiries invited.

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[1]System intact means no modifications of hardware. Failures caused by unsuccessful experimentation can not be covered under warranty. Be careful before you modify. We cannot be responsible for a system whose integrity was breached and/or altered. Gecko Systems, CareBot, GeckoFrame, and GeckoBus are registered trademarks of Gecko Systems, Inc. Windows 95/NT are registered trademarks of Microsoft Corporation.

January 9, 1999 • *FIRST 1999 Kick-Off Workshop*

Manchester, N.H—www.usfirst.org

The kick-off for the 1999 For Inspiration And Recognition of Science and Technology (FIRST) competition. Rules and regulations for the '99 competition will be presented. See page 61 for information on how to contact FIRST.

January 19-22, 1999 • *Artificial Life and Robotics*

Beppu, Oita, Japan—http://AROB.cc.oita-u.ac.jp/

One objective of the fourth international symposium (AROB 4th '99) on artificial life and robotics is to form research groups. These standing groups will investigate the various aspects of artificial life and their application to robotics.

February 21, 1999 • *First Annual Northeast Indiana Robot Games*

Fort Wayne, Indiana – www.geocities.com/CapeCanaveral/Launchpad/8735/

A Sumo wrestling event in three classes, Stock (an unmodified Lynxmotion Micromouse), Modified (modifications allowed to wheels and motors), and Open (any robot that fits the listed specifications).

March 2-4,1999 • *Nashville '99, Advanced Productivity Exposition*

Nashville, Tennessee – www.sme.org

March 15, 1999 • *APEC Micromouse Contest*

Dallas, Texas – www.apec-conf.org

Held in conjunction with APEC '99 (Applied Power Electronics Conference and Exposition) March 14-18, which focuses on the applied aspects of power electronics, ranging from circuit design to marketing, the micromouse maze contest attracts foreign and domestic teams .

March 22-25, 1999 • *Westec '99 Exposition and Conference*

Los Angeles, California – www.sme.org

Annual metalworking and manufacturing exposition, held at the Los Angeles Convention Center, will include a new metal forming and fabrication pavilion and job shop pavilion.

April 18, 1999 *Trinity College Fire-Fighting Home Robot Contest*

Hartford, Connecticut
www.trincoll.edu/robot

The challenge for entrants is to produc a robot that can move through a mode of a single floor house, detect fire and pu it out. There is a junior division for higl school students and younger, and a senio division. Other events include seminar and a robotics exhibition. For informa tion, contact jmendel141@aol.com. *See RS&T's Premier Collector's Edition fo robot construction ideas. Also see www.RobotMag.com.*

April 22-24, 1999 *FIRST National Championship*

Orlando, Florida (EPCOT Center, Walt Disney World) – www.usfirst.org

See the article on page 6 and the calenda on page 41 for more information.

Meet the GROWBOT™

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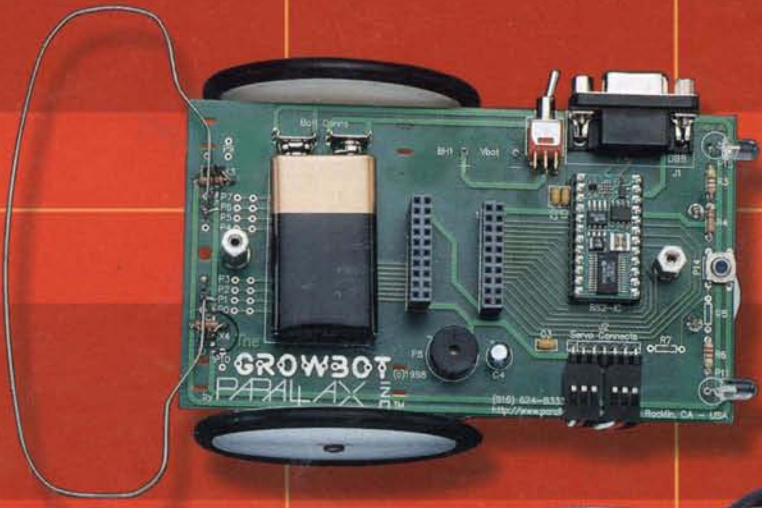
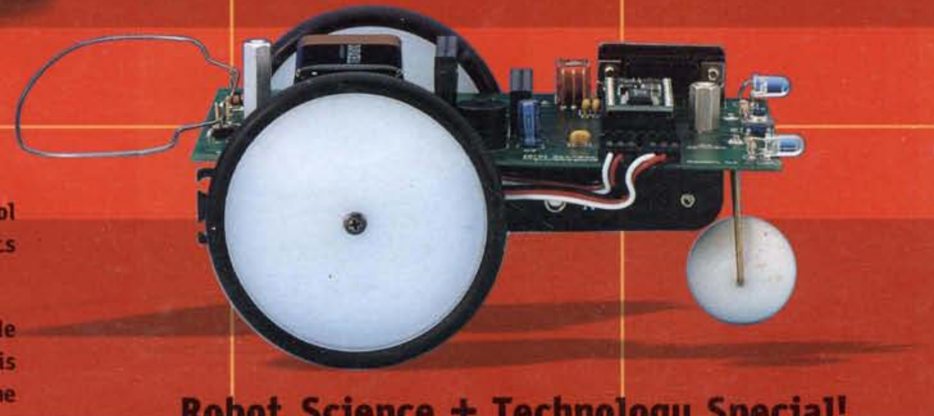
Save $30! Order your GrowBot by 1/15/99!



Easy-to-build kit. The GrowBot is a robotic kit designed around the Parallax BS2-IC module. GrowBot's standard I/O devices include a bumper, photo-resistor light sensors, a piezo speaker, LED lights, and servo drivetrain. GrowBot requires two hours to build using a soldering iron, needle-nose pliers, a small phillips screwdriver and a hobby knife. BS2-IC module, software and documentation included.



BASIC Stamp® expandability.
The BS2-IC controls the GrowBot by executing up to 500 lines of PBASIC code from it's non-volatile EEPROM. PULSOUT and FREQOUT commands control the servos and speaker, and IN detects closure of the bumper switch.

The BS2-IC module has 16 I/Os available for GrowBot control, and each is brought to the AppModule header in the middle of the GrowBot.

AppModules include:

Breadboard Prototype area with wire jumpers (#29114 - $29)

Through-hole Prototype area for point-to-point solder or wire wrapping (#29110 - $19)

See http://www.parallaxinc.com for details on new AppMods including the mobile digital recording studio, LED display terminal, and IR proximity sensor.

Robot Science + Technology Special!

$149 introductory price (+ shipping) through January 15, 1999 (regular $179).

Assembly instructions. Assembly instructions are picture-oriented and descriptive, making it an ideal project for parent-child combinations for age 12 and above.

December 25th Christmas Day Technical Support: Christmas Day technical support 7 a.m. to 4 p.m. PST at (916) 624-8333.

Happy Holidays from:

PARALLAX INC

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