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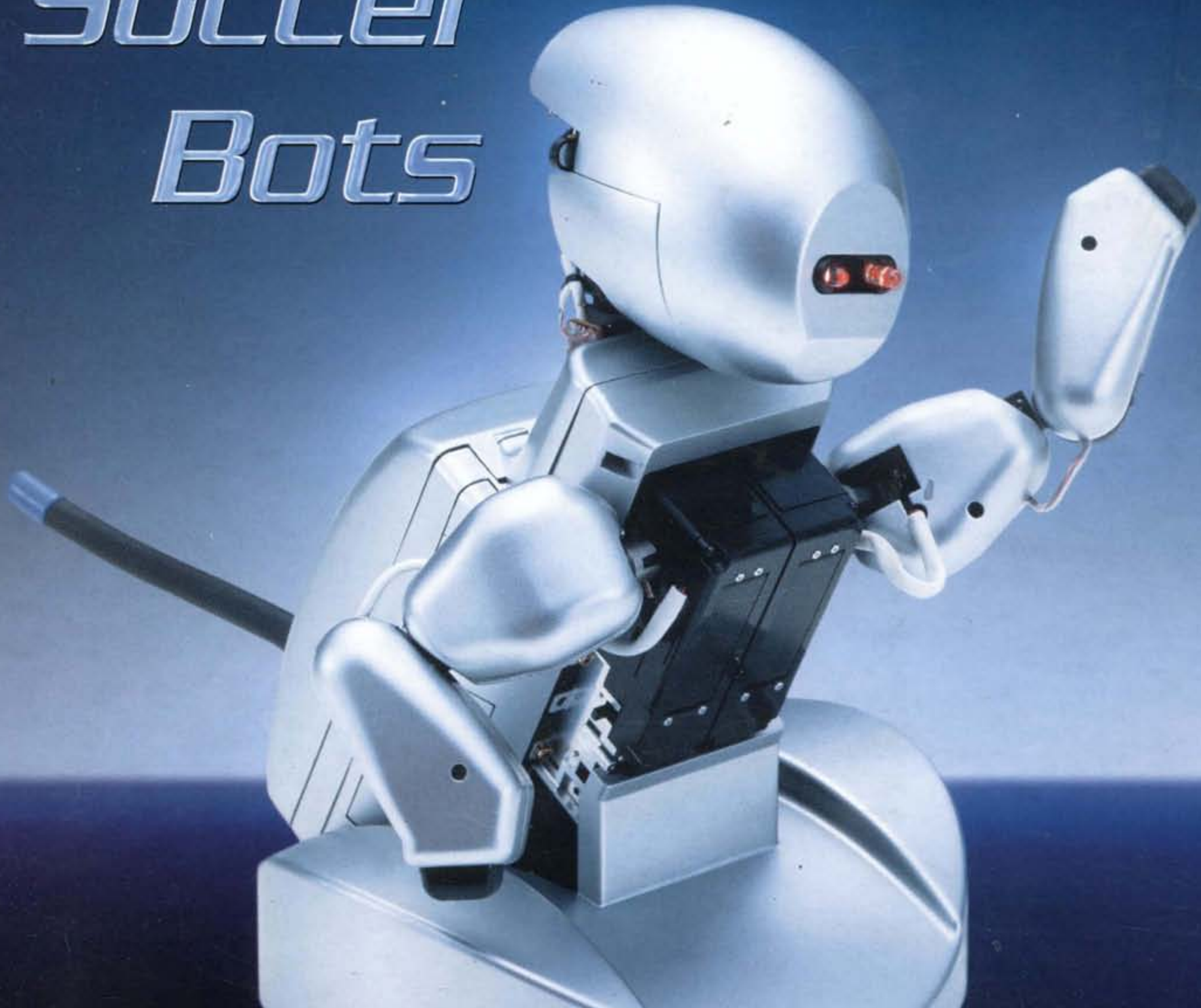
ROBOT science & technology

THE THIRD ISSUE • NOV 1998

Autonomous Soccer Bots



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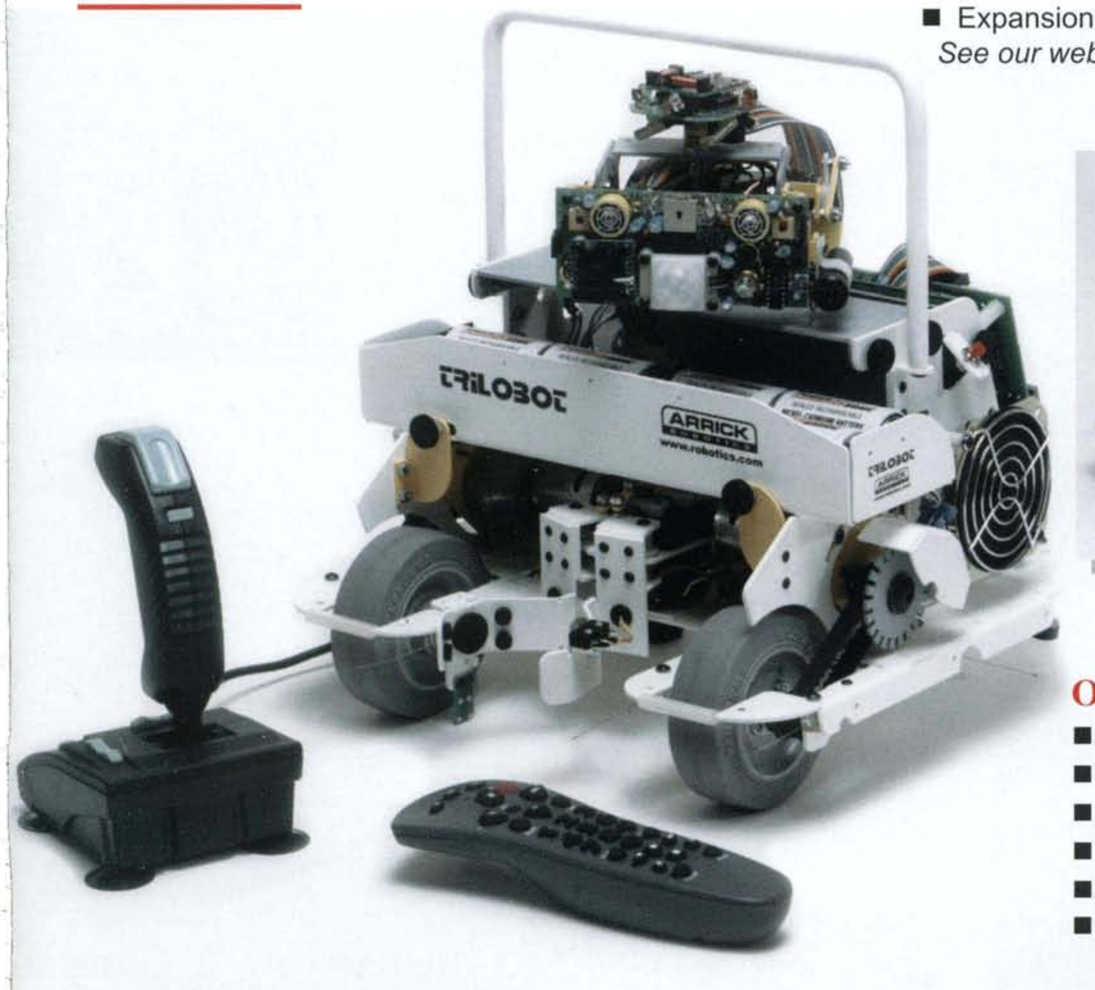

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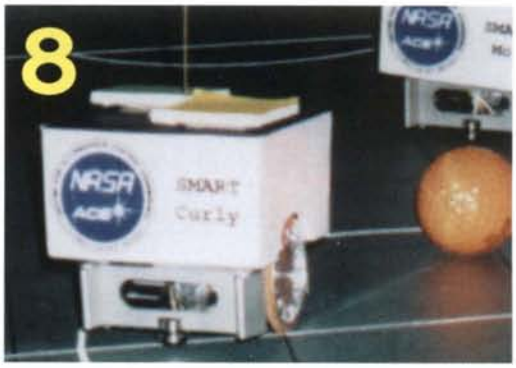
Departments

Features

Intelligent Soccer Robots: Part 1



by Mohammed Jamshidi, PhD, Denise Padilla & Marco de Oliveira

Fuzzy logic and control—helping robots play better soccer at NASA's ACE, U of New Mexico.

Plastic Gear Fabrication

by Tom Durkin & Rick Hahn at RS&T Labs

Reduce the weight and cost of your robot's gear train by duplicating metal gears in lightweight plastic. In the third in our series of fabrication articles, RS&T features editor Tom Durkin and fabrication specialist Rick Hahn guide you step-by-step.

Doomsday by Alfred E Hummin

Constructing a Com Robot: Part 1

by Ronni Katz, veteran robot wa

First Step: Put mind in gear be attaching gears to robot.

Cover Design: Iris Gilbert

Sony Corporation's autonomous entertainment robot poses with wheels on. To see the plug'n'play *legs* on this beautiful quadruped, the soccer playing version, check out our centerfold. (original photo courtesy Sony)

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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

I'm *thrilled* to accept FIRST's invitation to judge at the NASA AMES regional open competition in Hangar One at Mountain View, CA. FIRST (For Inspiration and Recognition of Science and Technology) has an enviable track record for improving our children's education. Every year, thousands of high school students learn teamwork and engineering while building a remotely controlled robot, competing their way up to national tournament at Disney's EPCOT center near Orlando. Be assured that RS&T will cc FIRST closely in the months ahead.

(My advice to high school teachers; visit www.usfirst.org to start your school's involvement. You'll w to find a corporate sponsor and register soon. See our Events Calendar on page 64.)

Readers will notice many improvements, starting with this, our third, issue. Although we've recei about a gazillion kudos for our print quality, our layout, graphics and design (thanks to Dave, Electric Page, and Commerce Printing), I also want to make RS&T the most useful and accu technical magazine in the world. This will take time, but I have good reason for approaching goal optimistically: just go to page 48 to see our newest crew members.

Here are two improvements: Because we've added such excellent team players to the editc office, we're able to meet our goal of being a *true monthly* magazine. Also, we're now ready to t renewals and new subscriptions for *twelve* issues, while keeping the price low. See page 49.

Since our first issue, educators, students and self-trained robot builders have sent a bag ful welcome guidance for our editorial direction. A lot of folks want to use RS&T as an educatic tool or a learning medium, and I wholeheartedly agree. (They've touched a warm spot in the h of our demographic analysis.) Humanity urgently needs an easy-to-read, heavily illustrated ma zine about one of the most important technologies of the fast-approaching millennium. With y support, RS&T will take the mission.

Are the articles in this issue too complicated? Look closely. Our authors try to explain comp subjects with simple words. So if an article seems too tough to tackle, concentrate on each thou until you truly understand it. Do the math yourself. Let me know which articles are most usefu you. **Will MIT's newly configured COG brighten your holidays?**

The coming December Issue looks *incredibly* packed with something for everyone. We're conti ing to run our series on micromouse search algorithms, fuzzy control of autonomous soccerb and kitchen-based plastic fabrication. We also have a line-up of robots you'll want to buy. Hey, *Christmas, the most commercial time of the year!* So look forward to reviewing commerci available robots, from $40 to $4000.

That's enough chat for now. Let's get to work, learning by playing with robots.

Michael A Greene

P.S.—Check out this month's centerfold. And remember, it's *not* a "dog;" it's Sony's entertainment robot, known in some laboratories as the *RoboPet*.

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Random Firings

Where is humankind headed?

Just look at the fringe of society.

Fringe thinkers are on the leading edge.

They are already *there* today,

Where we will be tomorrow.

Veteran robot builders will remember the naive enthusiasm that accompanied the emerging field of Artificial Intelligence when it was new. We thought that this quantum advance in human knowledge, when implemented by computer programs, would give us real robots like the preeminently useful *Rosie Jetson* or perhaps the *Robbie* genre from the movie *Forbidden Planet*. And then Arthur C. Clarke envisioned a scarier result of machine intelligence in the classic *2001: A Space Odyssey*. Today we are wiser (of course) and less prone to believe optimistic prognostications of sophisticated robots like the *Star Trek Commander Data* type. This somewhat depressing attitude is unfounded: there are *great* robots in our world, and RS&T is bringing them to you.

> **There are Great Robots in the world, and RS&T is bringing them to you.**

The brilliant folks at the 1998 conference of the American Association for Artificial Intelligence demonstrated some very cool "real live" robots with state-of-the-art smarts. RS&T was there to see some exciting and successful "Find Life on Mars" contestants, learn about COG's face awareness logic, and play with a trio of soccer-playing *RoboPets*. (We're told Sony doesn't refer to them as "dogs," but they wag their tails and walk on all fours, sooo…)

Who else but the brainy super-geeks at AAAI would hold a cocktail party where the hors d'oeuvres were served by mobile mechanical autonomous waiters?

Who else *could*? Readers can be sure that stories like these are in RS&T's lineup, starting this issue.

Puppies playing soccer? We saw it first-hand. In this issue, Carnegie Mellon's Professor Manuela Veloso and William Uther, and Sony's Masahiro Fujita explain how they programmed Sony's entertainment robots to recognize their position on a small indoor soccer field, attack the ball, and kick it toward the goal. Although Sony's proprietary machinery and base software are pretty hush-hush, you might pick up a few construction hints through our exclusive photographs. See page 28.

Other bots play a lively game of soccer, too. RS&T has been following the micro-robot soccer championships for several years now. Our friend Professor Jong-Hwon Kim at the Korea Advanced Institute of Science and Technology (KAIST) has been touring the world with the Federation of International Robot-soccer Association (FIRA). These cube-shaped fuzzy microprocessors on wheels are introduced in this issue by Professor Mo Jamshidi of NASA's Center For Autonomous Control Engineering at the University of New Mexico. See page 8.

And we won't forget *RoboCup* in future issues. These larger machines are fast and powerful enough to knock you off your feet. See page 38 for some preview photos of Newton Lab's soccerbots in our photomontage of the Mondo-Tronics Robo Expo tour.

The Robo Expo tour, first mentioned in the July RS&T calendar of events, was a huge success, drawing thousands at each city. Participants seemed to enjoy viewing the latest in robot kits, including Lego's programmable MindStorms kit, Parallax's Basic Stamp GrowBot and Lynxmotion's Hexapod. But we at the RS&T table were equally fascinated by the *audience*. The Silicon Valley garage-based robot builders, students, educators, Boeing engineers, and just plain folks showed us more evidence that thousands of robot builders, both novice and veteran, are alive and working on our next generation of low-cost consumer robot applications. The robot societies are alive and well. My favorite robot builder is one of the youngest: see 13-year-old Garrett Myrick and his minimalist walking creation on page 39.

And at the Seattle Robo Expo, we finally met author Karl Lunt, who has supported us for several years, before we began actually printing the magazine. So RS&T photographer Iris Gilbert immediately shot him on sight. See his latest article , modifying Futaba servos, on page 22.

It looked like a meeting of some underground movement. Which, indeed, it was.

We were disappointed to see ClineWorks' *Robotica* cancelled after legal action from *Robot Wars*, especially after RW's partners didn't hold their own 1998 event.

In fact, on Oct 6, a legal notice at www.RobotWars.com announced that RW founder Marc Thorpe has put his half of *Robot Wars* on the auction block. Bids start at $250,000. (*Robot Wars* 1997 was a *blast*. See www.RobotMag.com.)

But the competitors themselves are undaunted: The fledgling Society of Robotic Combat held its inaugural meeting last month in a dimly lit room filled with, um, eccentric geniuses who like to smash robot against robot for fun. (Expensive fun, indeed.) The personalities in the room were legends in the robotic combat community, but somehow we at RS&T think they prefer to remain incognito. It looked and sounded like a meeting of some underground resistance movement. Which, indeed, it was.

RS&T will continue to infiltrate the ranks of the SORC army, bringing you construction articles to help you design and build your own radio-controlled or autonomous killing machine. Check out our first installment of Ronni Katz' *Chew Toy* articles on page 51. Also be sure to read Carlo Bertocchini's informative and detailed article about over-driving DC motors on page 14.

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

For hard-core do-it-yourselfers, features editor Tom Durkin and fabrication artist Rick Hahn built a step-by-step how-to article detailing the results of casting a light-but-strong plastic copy of a heavy steel spur gear. See page 19.

Programmers who want to challenge their problem solving wits on a maze solving micromouse will find Dr. Tak Auyeung's depth-first search algorithm to be an exciting zig-zaggy step in the right direction. See page 40.

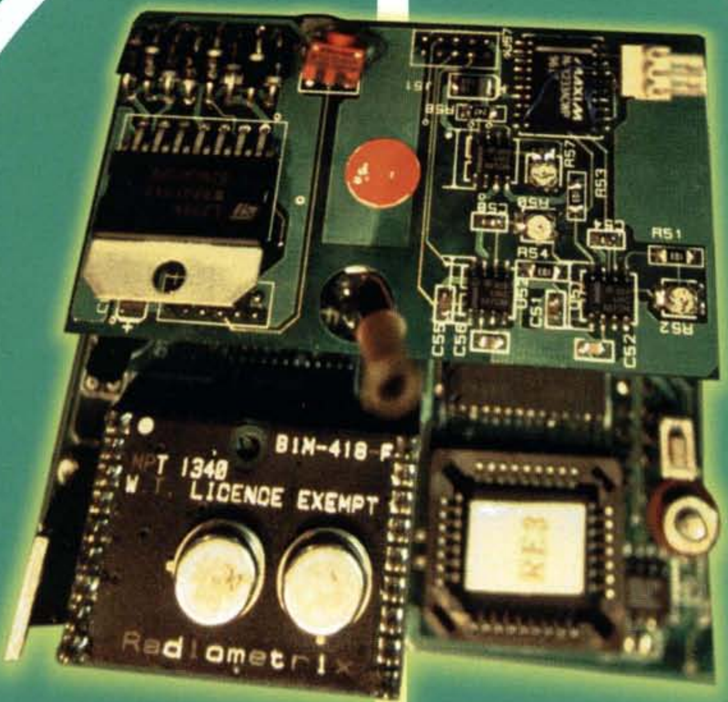
Who are we? Where are we going?

I'm proud to announce we've added some very experienced and energetic talent. See our new smiling faces on page 48. We're all hard at work on the Christmas issue now.

The Christmas Issue is shaping up to be a great one, with an emphasis on *fun*. To prepare stories for the Christmas and January issues, we logged a lot of air miles interviewing geniuses, fact-checking stories and photographing robots in San Francisco, Seattle, and Madison.

Isn't *that* what your robot magazine should do?

Intelligent Evolving Soccer Robots, Part I



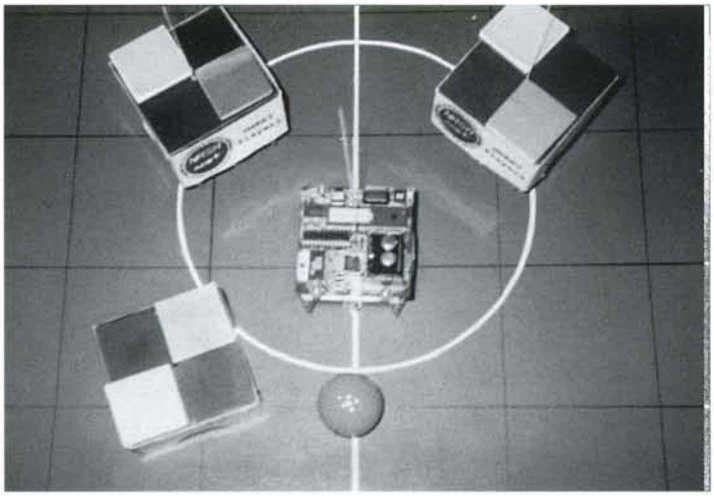
by Mohammed Jamshidi, Ph.D., Denise D. Padilla, and Marco de Oliveira

In today's fast moving technological world, intelligent techniques of incorporating reasoning, learning, perception, and coordination into analysis and design philosophies of systems seem to be an unavoidable eventuality. Today soft computing—fuzzy logic, neural networks, genetic programming, and probabilistic reasoning—have resulted in more user-friendly products that learn to adopt their user's operational characteristics.

At the NASA Center for Autonomous Control Engineering (ACE) at the University of New Mexico, students and faculty researchers are using soft computing techniques to create autonomous control paradigms to provide 'intelligence' to robots. One of the current research topics at NASA ACE in robotics is the use of multiple autonomous robots for the cooperative execution of tasks. These robots present several advantages, such as robustness through redundancy in numbers, reduced size and weight, and lower production cost, over monolithic robot approaches. Fuzzy logic and fuzzy control, a sensor-fusion, and rule hierarchy approach allow these complex systems to function. Finally, a hierarchical fuzzy system optimized through evolutionary methods, acts as a controller, and in conjunction with an algorithm, are employed by two teams of opposing robots to play a soccer match. In this Part I of a two part series, fuzzy logic and fuzzy control are discussed. Fuzzy control and fuzzy behavior for robot soccer will be explored in Part II.

In robot soccer, two teams of robot agents compete against each other for the control of an orange golf ball, which should be moved into the opposing team's goal. Many of the rules of human soccer apply (e.g., fouls, half-times, penalty-kick) and the playing field is a green flat surface with white standard soccer markings and white containing walls. (See [1] and [2] at the end of this article.)

As described by Tunstel [3], and implemented by our group, each robot's overall behavior emerges from the interaction between multiple fuzzy logic controllers, each



responsible for a distinct behavior. In the case of the robot soccer test bed, a robot's behavior is governed by the fuzzy modules *attack*, *defend*, *pass*, *intercept*, *block*, *shoot*, *avoid*, and supported by the non-fuzzy modules *sense*, *talk*, *move*, *kick*, and *turn*. Fuzzy logic controllers implement control algorithms consisting of linguistic rules, usually of the form *IF x is A and y is B then z is C* (x, y, z being the input and output variables) and an inference engine, which executes and aggregates the rules' output. The rules represent mappings between input and output variables.

WHAT IS FUZZY LOGIC?

Zadeh [4], in his seminal paper, chose the word "fuzzy" for the continuum of logical values between 0 (completely false) and 1 (completely true). The theory of fuzzy logic deals with two problems: (1) the fuzzy set theory, which deals with the ambiguity found in semantics, and (2) the

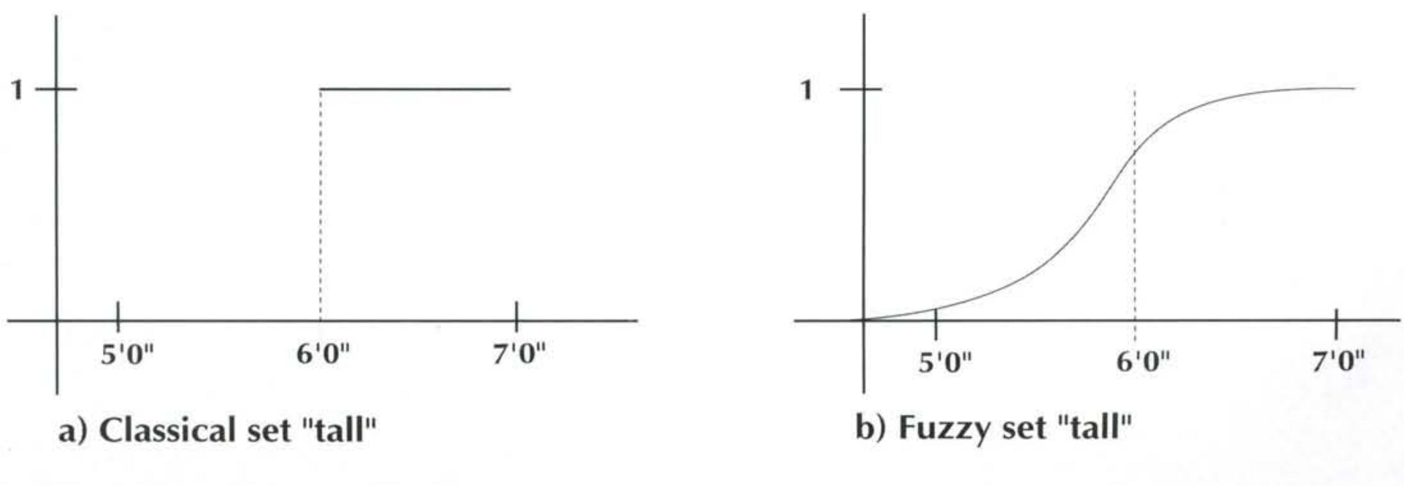


Figure 1: Two set-membership functions for the linguistic variable "tall."

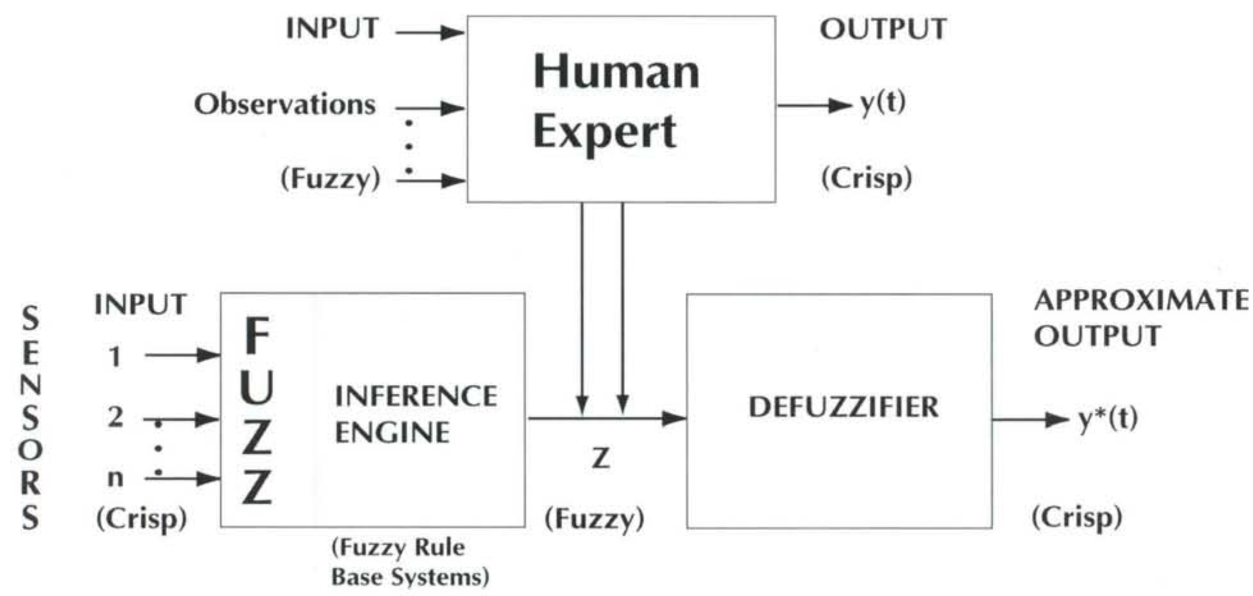
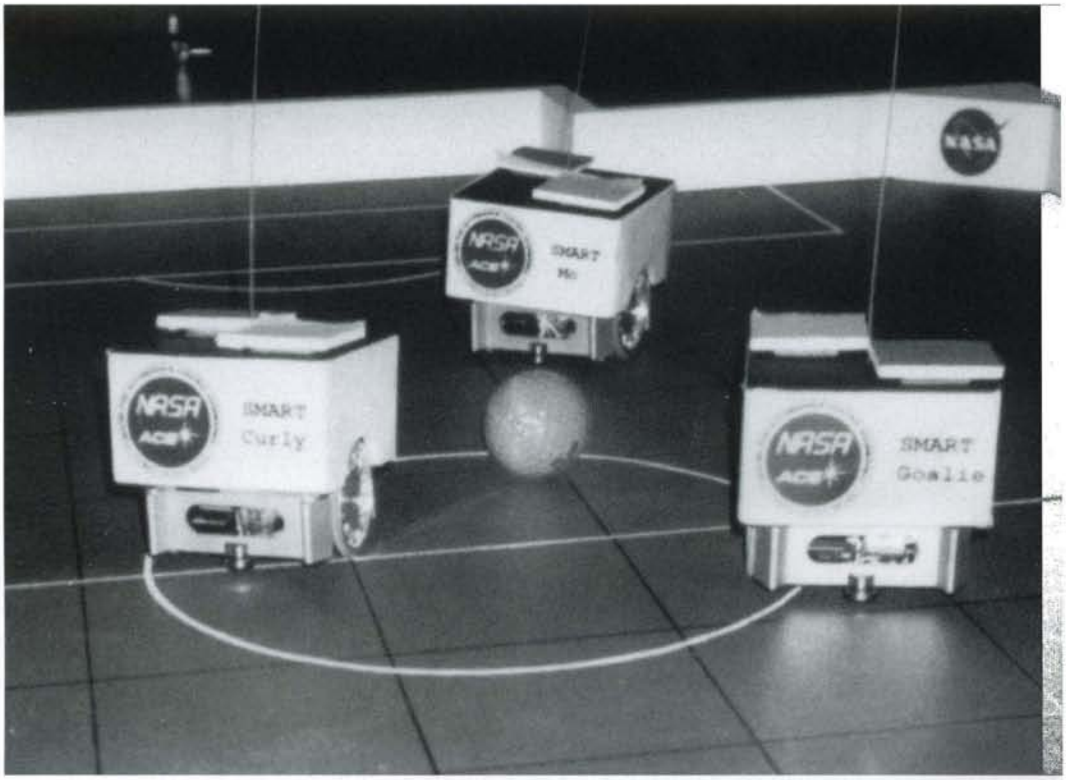


Figure 2: A concept definiton of a fuzzy control system.

fuzzy measurement theory, which deals with the ambiguous nature of judgments and evaluations.

The primary motivation or "banner" of fuzzy logic is exploiting tolerance for some inexactness and imprecision. Precision is often very costly, so if a problem does not require high precision, one should not have to pay for it. If a car is not required to be parked within an exact distance from the curb, why spend any more time than necessary as long as it is legally parked? Fuzzy logic and classical logic differ in the sense that the former can handle both symbolic and numerical manipulation, while the latter can handle symbolic manipulation only. In a broad sense, fuzzy logic is a union of fuzzy (fuzzified) crisp logic [5]. To quote Zadeh, "Fuzzy logic's primary aim is to provide a formal, computationally-oriented system of concepts and techniques for dealing with modes of reasoning which are approximate rather than exact. Thus, in fuzzy logic, exact (crisp) reasoning is considered to be the limiting case of approximate reasoning. In fuzzy logic, one can see that everything is a matter of degree.

In an attempt to translate the crisp knowledge in a process, such as voltage across a terminal, to linguistic or fuzzy knowledge—that is, to go



NASA ACE's Robot Soccer Team

Rule	If/Then
1	**IF** temperature IS *cold* **THEN** fan speed IS *high*
2	**IF** temperature IS *cool* **THEN** fan speed IS *medium*
3	**IF** temperature IS *warm* **THEN** fan speed IS *low*
4	**IF** temperature IS *hot* **THEN** fan speed IS *idle*

through the process of "fuzzification"—one must make the binary input and output variable members of some fuzzy set. Fuzzy sets may be represented by a mathematical formulation often known as the membership function. A membership value of zero corresponds to a value that is definitely not an element of the fuzzy set, while a value of one corresponds to the case where the element is definitely a member of the set. In fuzzy logic, like binary logic, operations such as union, intersection, complement, OR, AND, etc., are all defined. Figure 1 shows two set-membership functions for the fuzzy variable "tall." In Figure 1a, a height of 6'0" to 7'0" has full membership in the classical set "tall," whereas any height less than 6'0" does not belong to this set. In Figure 1b, one can see a gradual transition from zero membership to complete membership with increasing height in the fuzzy set "tall." Here different persons with different heights are only "tall" in accordance to their degree of membership.

WHAT IS FUZZY LOGIC CONTROL?

Fuzzy control systems are rule-based systems in which a set of so-called fuzzy rules represents a control decision mechanism that substitutes for or emulates a skilled human operator. As shown in Figure 2, the human operator observes quantities by reading a meter or assessing a chart (i.e., noting fuzzy variables), and then performing a definite action, such as pushing a knob or turning a wheel (i.e., providing a crisp action or output y). In a similar fashion, the fuzzy controller uses crisp data directly from a number of sensors; through the process of fuzzification these are changed to linguistic or fuzzy membership functions (fuzzified). The fuzzified data then goes through a set of fuzzy "IF-THEN" rules in an inference engine and results in some fuzzy output(s) designated by variable z. The fuzzy output(s) will then be changed back into crisp values through a process called "defuzzification" by some weighted average method, such as the "center of gravity" method. The result is a value denoted by y*. In this way, the designer has obtained an approximate output y* for the actual output y.

A fuzzy controller typically takes the form of a set of IF-THEN rules whose antecedents (IF part) and consequents (THEN part) are themselves membership functions. Consequents from different rules are numerically combined and are then collapsed (typically taking the centroid of the combined distribution) to yield a real-number (binary) output. Within the framework of a fuzzy expert system, like regular expert systems, typical rules can be the result of a human operator's knowledge, e.g. for a temperature controller.

Here the linguistic variables *cold*, *cool*, *warm*, and *hot*, are labels that refer to the set of overlapping values shown in Figure 3. These triangular shaped values are called membership functions.

→

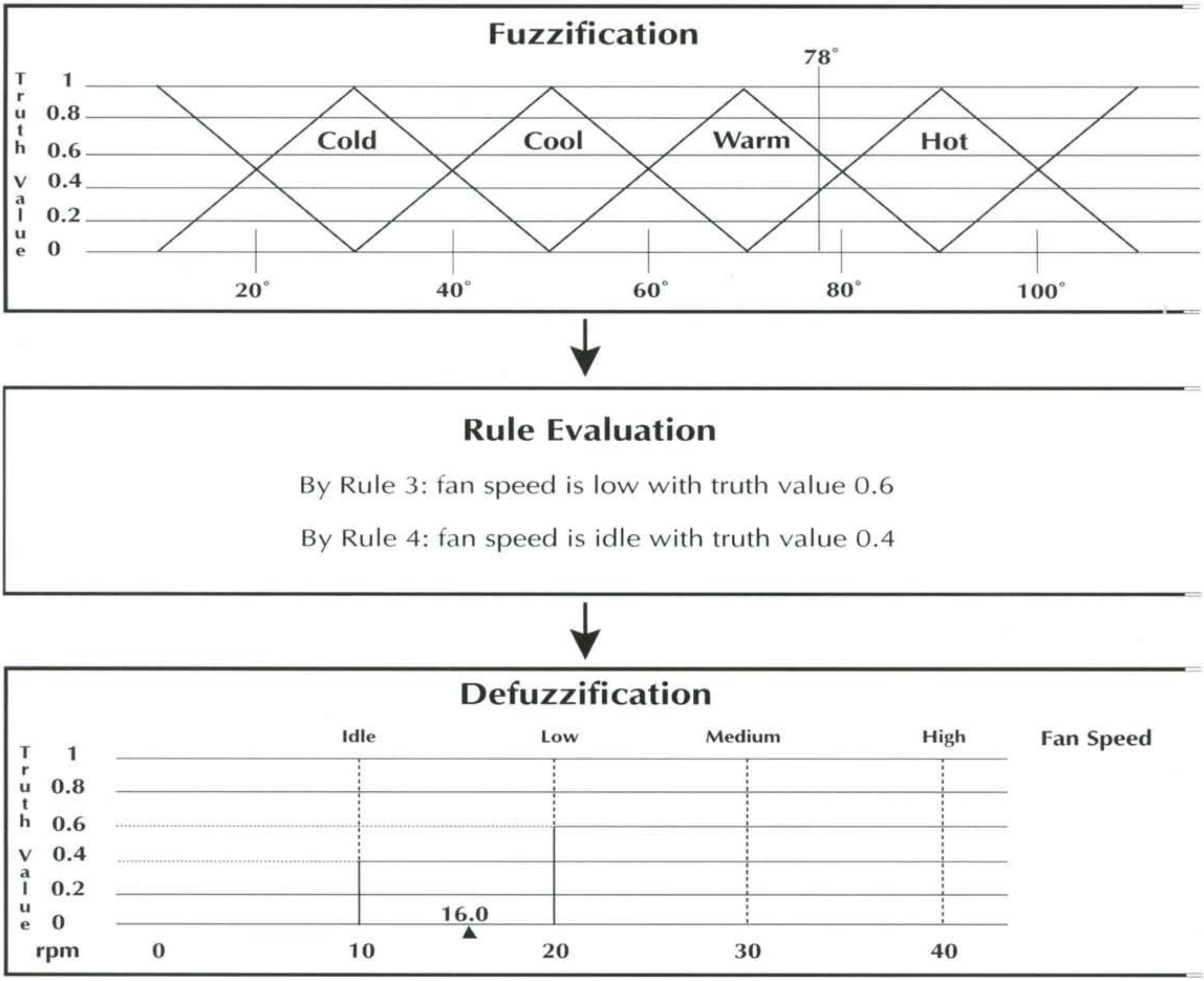


Figure 3:The Fuzzy Inference Process.

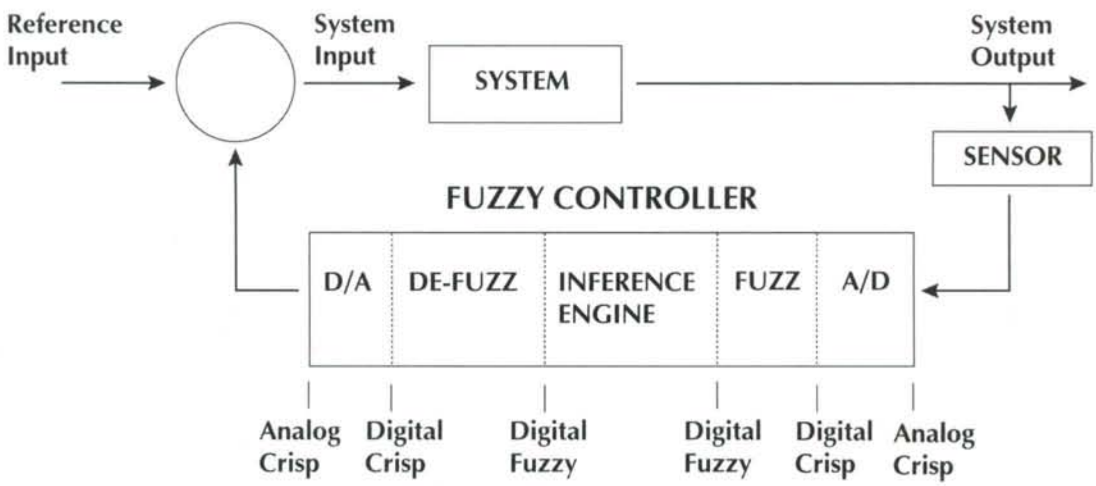


Figure 4: Block Diagram for a typical fuzzy control system showing fuzzifier (FUZZ), defuzzifier (DE-FUZZ), and inference engine

A fuzzy controller works similar to a conventional system: it accepts an input value, performs some calculations, and generates an output value. This process is called the *Fuzzy Inference Process* and works in three steps illustrated in Figure 3: (a) *Fuzzification* where a crisp input is translated into a fuzzy value, (b) *Rule Evaluation*, where the fuzzy output truth values are computed, and (c) *Defuzzification* where the fuzzy output is translated to a crisp value.

Denise Padilla and Professor Mohammed Jamshidi with their soccer-playing bots.

During the fuzzification step the crisp temperature value of 78°F is input and translated into fuzzy truth values. For this example, 78° F is fuzzified into *warm* with a truth value of 0.6 (or 60%) and *hot* with truth value 0.4 (or 40%).

During the rule evaluation step, the entire set of rules is evaluated and some rules may be fired. For a temperature of 78°F only the last two of the four rules will fire. Specifically, using rule three the fan speed will be *low* with degree of truth 0.6. Similarly, using rule four the fan speed will be *idle* with degree of truth 0.4.

During the defuzzification step the 60% *low* and 40% *idle* labels are combined using a calculation method called the *Center of Gravity* (COG) in order to produce the crisp output value of 16.0 RPM for the fan speed. This value is obtained by use of the following equation:

$$\text{rpm} = (0.6 [20] + 0.4 [10]) / (0.6 + 0.4) = 16 / 1 = 16$$

In any practical system, such as an air conditioning system, the user or an operator often fine-tunes, tweaks, and adjusts the knobs until the desired cool (or hot) air can be felt with the desired speed. Such operator knowledge can be utilized in the design of a fuzzy controller for an air conditioning unit system. One of the most common ways of designing a fuzzy controller is through "fuzzy rule-based systems." Figure 4 shows a typical fuzzy control architecture. The controller shows the processes of fuzzification, (i.e., binary to fuzzy transformation) and defuzzification (i.e., fuzzy to binary transformation).

In the second part of this two part series, fuzzy logic control and fuzzy behavior for robot soccer, and evolving intelligent robots through genetic algorithms will be explored. ***Don't miss it!***

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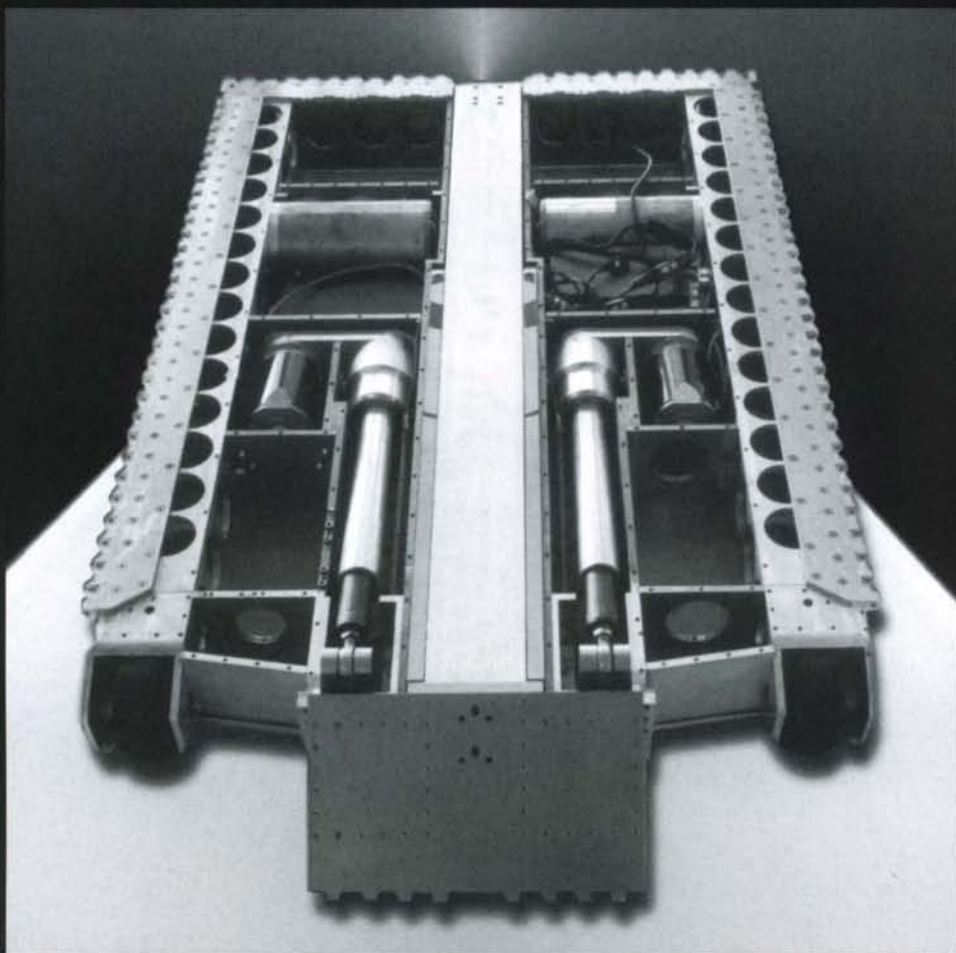
Motor Selection and Performance

by Carlo Bertocchini



Robot Wars heavyweight champion **BioHazard** without its protective armor. This robot uses four **PMDC electric motors**, two for locomotion and two to power its devastating arm.

Building a robot requires many decisions. Everything from the type of sensors you want, to the color you will want to paint it. Some of these decisions are trivial, others will make or break your robot. One decision that is in the make-or-break category concerns motors; not just which ones to use but how to optimize their performance.

Most combat competition robots use a particular kind of motor, the Direct Current Permanent Magnet (PMDC) motor. We will limit our discussion to PMDC motors.

Let's look at some of the factors you should consider before you choose a motor.

Power

First, you should have a good idea of the power that you will require.

Motor power is rated in either watts or horsepower (746 watts equal one horsepower). Small motors, of the type that are used in many toys, are fine for a line-follower, or cat annoyer. If, on the other hand, your plan is to dominate the heavyweight class at Robot Wars™, you will require heavyweight motors. The larger class of motor can be as much as 1,000 times more powerful than the smaller toy motors.

> Turn a pipsqueak into a brute? More voltage.

A small toy motor might operate at three volts and draw two amps, for an input requirement of six watts (volts x amps = watts). If the motor is 50% efficient, it will produce three watts of power. At the other end of our spectrum are the robot warrior motors. One of these might operate at 48 volts and draw hundreds of amps, for a peak power output of perhaps five horsepower or more. Two of these motors can accelerate a 180-pound robot warrior to 25+ mph in just a few feet, with tires screaming. One 1997 heavyweight (Kill-O-Amp) had motors that extracted 1000+ amps from its high output car battery! The power that your robot will require is probably somewhere between these two extremes.

Factors that will affect your power requirements include things like operating surface. Much more power is required to roll on carpet than on a hard surface. Likewise, going uphill will increase your power needs. Soft tires have more rolling resistance than hard tires (this will also increase the power requirements). Do you have an efficient drive train, or power-robbing worm gears? How fast do you want to go?

An internal combustion engine produces its peak horsepower at about 90% of its maximum rpm, and peak torque is produced at about 50% of maximum rpm. The higher the rpm, the more energy it consumes. Compare this to the PMDC motor, which consumes the most energy and develops its peak torque at zero rpm. It consumes very little energy at maximum rpm, and it produces its peak horsepower at 50% of its unloaded rpm.

At 50% of maximum speed, the PMDC motor will draw 1/2 of its maximum stalled current. Unfortunately, much of the current going into the motor at this high power level is turned into heat. It is much better to run the motor at its speed of peak efficiency or higher. Speed of peak efficiency varies from motor to motor, but it is usually in the neighborhood of 80% of maximum speed.

Many motors are rated to operate continuously at a certain voltage. You can increase the power of your motor by increasing the voltage. The trade-off is that the motor will overheat unless you limit the duty cycle. A motor that draws 12 amps at 12 volts, and is 65% efficient, produces 94 watts of power (12x12x.65). If you run that same motor on 24 volts, it will draw twice as much current, and produce 374 watts, or four times more power. Your 94-watt weakling is now a 1/2 horsepower brute! That's not the whole story though. The higher the voltage at which you operate your motor, the more efficient it becomes, but higher voltage also means higher rpm, so you need to gear it down more for a given speed. If your drive train is inefficient, you may lose those efficiency gains.

A big factor in choosing a motor is the conditions under which it will operate. Will the motor run continuously, or will it have a short duty cycle? A motor can be pushed much harder if it is used for a short time, and then allowed to cool. In fact, heat is probably the biggest enemy of the PMDC motor.

Heat

Heat can destroy a motor in several ways. Most PMDC motors have ferrite magnets. These magnets can become permanently demagnetized if overheated. They can also be demagnetized by the magnetic fields produced when running the motor at a voltage higher than that for which it is rated. The flexible braided copper leads that feed current to the brushes (called shunts) can melt after just a few seconds of severe over-current. Even the heavy copper windings can melt. You don't want to use that expensive motor as a fuse, so make sure it can handle the heat!

Motor heating is proportional to the current squared times the resistance. Our 12-volt motor might have a resistance of .4 ohms. If you were to stall it, it would draw 30 amps. If you stall it at 24 volts, it would draw 60 amps, and since heating is a function of current squared, it would get four times as hot. Pushing sixty amps through a resistance of .4 ohms will generate 1440 watts of heat, about as much as an electric space heater. Imagine all the power of your portable heater concentrated into a lump of metal that weighs just a few pounds. You can see why survival time is limited.

The physical size of the motor that would best fit your need is in large part determined by the amount of heat that will be generated. Some people find it surprising that a 12-ounce motor can produce exactly the same amount of power as a five pound motor. The same formula for motor power is just as true for small motors as it is for large motors. The difference is in how long that power can be produced. The larger motor has a larger thermal mass, and can therefore absorb a lot more heat energy for a given temperature rise.

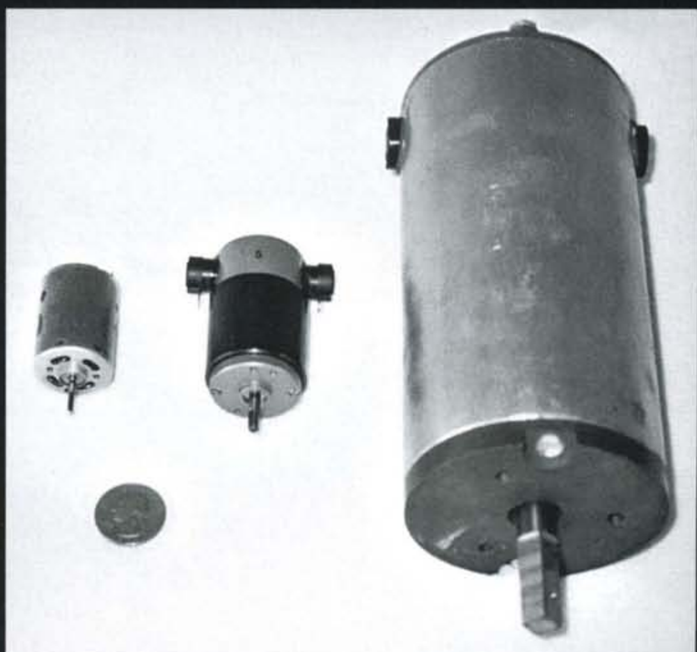
OK, you would like to over-volt your motor, but you are worried about damaging it. What should you do? First, you have to realize that you run the risk of destroying your motor if you choose to boost performance with this method. Here are some things you can do to minimize the risk:

Limit the duty cycle. If you run your motor say, one minute on, and five minutes off, it should survive. Cooling is critical for an over-driven motor. One Robot Wars™ heavyweight (La Machine) cooled its over-volted motors by directing the output of a ducted fan into them. These ducted fans are normally used for propulsion in model aircraft. They put out a *lot* of air.

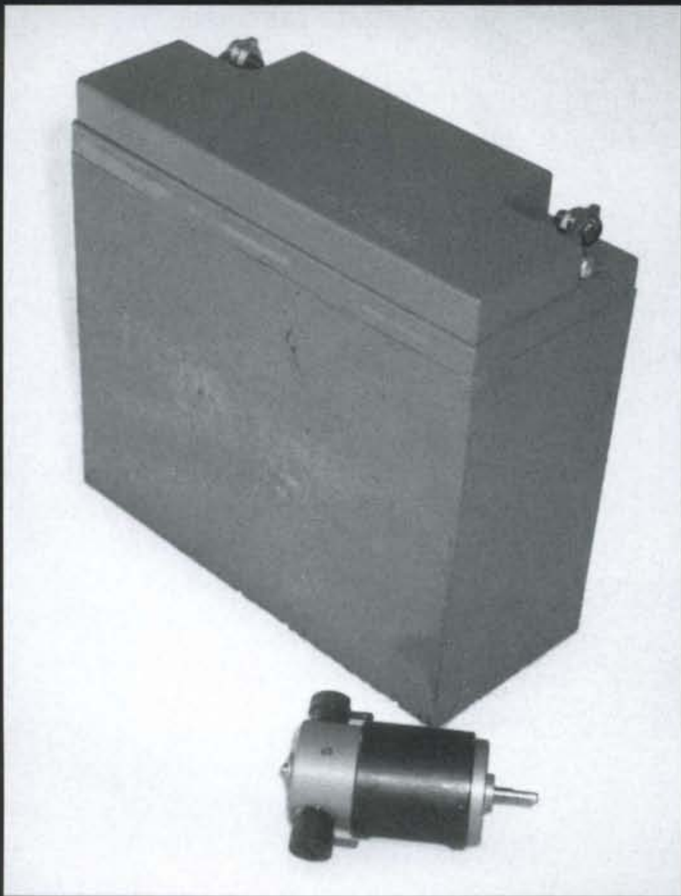
Put a resistor in series with the motor. If you choose a resistor that has the same resistance as the motor windings, the motor will only draw 1/2 the current at stall that it normally would. An interesting thing about this technique is that it has almost no effect on the motor's top speed. If you double the voltage, this will double the horsepower without increasing the heating when stalled. The best of both worlds, except we are forgetting that third world: efficiency. Efficiency will go down with this method. Don't forget to use very heavy-duty resistors. You might be better off using a long piece of wire, with high temperature insulation, as your resistor. An easier way to accomplish this same effect is to use batteries that are limited in the amount of current that they can produce. The problem here is that you will often be pushing your battery to output levels that will shorten its useful life.

High Performance Motors

If you are still not satisfied with the performance of your motor, (and money is no object), you might want to purchase a *high performance* motor. High performance motors have one major difference (and several minor ones), from regular motors, in a word: efficiency. We have been discussing motors with 50 to 65% efficiency. That is the range for fair to very good ferrite magnet motors. When we step up to



A toy motor, a small high-performance motor, and one of the drive motors from a 180-pound robot.



With just five turns of heavy-gauge wire on its armature, this six ounce, rare earth magnet motor will draw every amp of current that this 15 pound battery can produce.

rare-earth magnets, we get into a whole new realm of performance. The efficiency figures for small rare-earth magnet motors range from about 80 to about 90 percent.

These magnets are made from either cobalt or neodymium. They are so strong that they are actually dangerous to handle. A moment's inattention may result in a nasty crush as your finger is caught between them. The added bonus with cobalt magnets is that they are very resistant to demagnetization. A motor with cobalt magnets is virtually immune to demagnetization, no matter how much voltage you pump into it, or how hot it gets. Motors with rare-earth magnets run much cooler than ferrite motors. While a ferrite motor turns about one-third of the power it consumes into heat, the rare-earth motor only wastes about 10 to 20% of the electricity you feed it.

Another class of high performance motor is the *brushless* PMDC motor. The brushes in an ordinary motor are the source of several problems. They spark and cause radio interference; they are a source of friction and they wear out. The brushless motors have sensors that detect the position of the rotor relative to the windings. This information is sent thousands of times each second to a special controller that energizes the windings at the optimum moment on each revolution of the motor. In a brushless motor the windings are stationary and the magnets spin; exactly the opposite of a conventional motor. This configuration is capable of much higher speeds. You can buy motors that spin at 50,000 rpm or more. The highest performance small PMDC motor that I am aware of is a military brushless motor. Ninety-three percent efficient, 7.5 horsepower, fits in your coffee mug.

We can't talk about getting the most from your motors without mentioning three other items that have a big effect on their performance.

Controller

An electronic speed controller (ESC) is a device that meters the flow of current to your motor. It does this by rapidly switching the current on and off, several hundred to several thousand times per second. Small motor ESCs are readily available at the hobby shop. These typically have four transistors, and some of them allow you to run the motor in both forward and reverse. Larger motors will require larger speed controllers. The controller used in my Robot Wars™ heavyweight is made by a company called Vantec. However,

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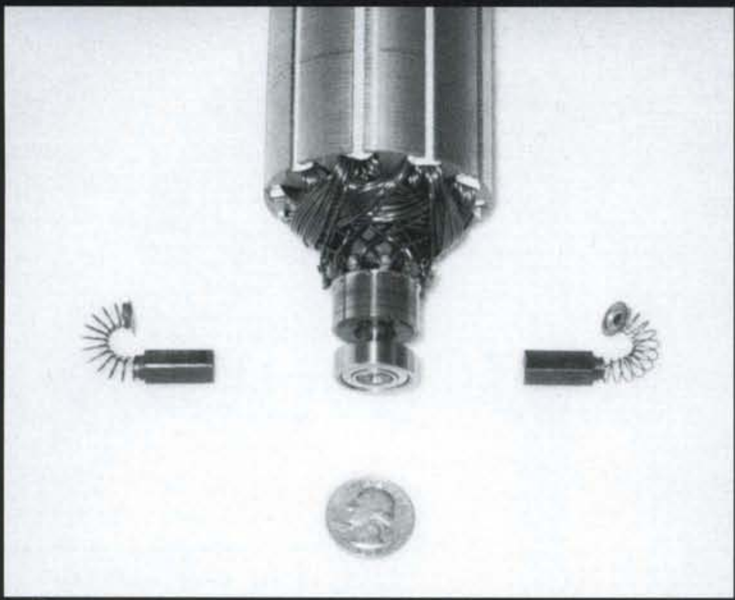


The business end of one of BioHazard's drive motors. The two graphite brushes supply current to the copper comutator.

even with its 48 transistors, I am pushing it beyond its design specs.

One way in which controllers from different companies differ is in the frequency at which they chop the current to the motor. High frequency controllers have two advantages, and two disadvantages over lower frequency controllers.

One of the advantages of higher frequency is smoother motor control, and more power available at partial throttle. The 12-volt motor in our example above has a stall current of 30 amps. At 20% of full speed, a low frequency controller is switching the current on for 20% of the time and off for 80%. During the 'on' time, the motor can only draw a maximum of 30 amps. During the off time, no current flows. The average current is about six amps. With a high switching frequency, the motor current would be almost constant because the motor's inductance keeps the current flowing during the controller's off time. A high frequency controller can push almost 30 amps into our motor, at any speed. This gives more torque at partial throttle.

The other advantage of high frequency is less motor heating. Let's say the motor is doing a task that requires an amount of torque that can be generated by five amps of current. The motor can generate much higher torque, so we throttle it to 20% 'on' time with our speed controller. In a low frequency speed controller, zero current flows for 80% of the time. Thus, 25 amps of current must flow during the on time, to get an average current of five amps. With a high frequency controller, the motor's inductance keeps the current flowing even during the 'off' time. Therefore, the current at any point in time is almost the same as the average current. Both controllers are putting out an average of five amps, so why is high frequency better? Let's take a closer look at the heating effects. Twenty-five amps of current will produce 25 times more heat than five amps of current (remember heating is proportional to current squared). In the low frequency controller, the current is only flowing 20% of the time. Therefore, the net heat generated in the motor in our example is five times higher than the same motor with a high frequency controller.

Now the bad news. High frequency controllers get warmer while operating, and require more heat sinking. Their second disadvantage is that they can generate radio frequency interference. This might cause problems in a radio-controlled robot.

Batteries

A thorough examination of the topic of batteries is beyond the scope of this article. However, I do want to mention one thing. Some of the performance figures that we have been discussing are for motors that are drawing hundreds of amps. If your battery cannot supply that amount of current, you won't see optimal performance. Try to buy a battery with current output that matches the current draw of your motors.

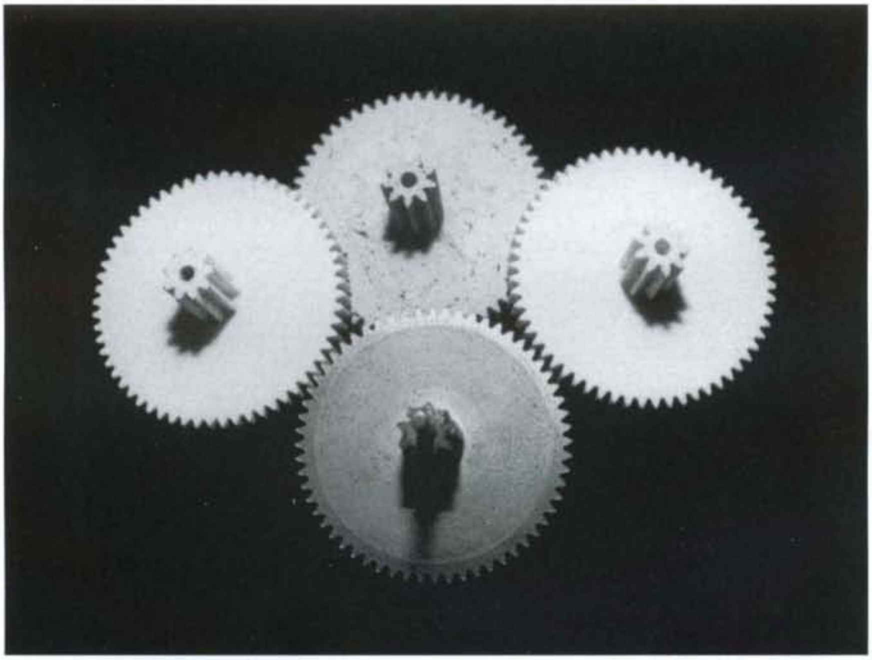
Drive Train

PMDC motors generally run at speeds so high that they cannot be bolted directly to a drive wheel. Some type of mechanical speed reduction is required. However, if you are not careful, you can lose those hard won performance gains by using an inefficient drive train. Gears, chains, and belts can have very high efficiency, but if poorly designed and constructed, they will turn much of your power into heat. Use ball bearings instead of bronze bushings wherever you can, and stay away from worm gears in performance applications. Don't let your drive train become a drive drain!

Carlo Bertocchini *is a mechanical designer from Belmont, California. His robot (BioHazard), has been the heavy weight 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.*

In robotics, the weight of the components of your robot can work for you—or against you. Th is the third article in our fabrication series. In this installment, we'll show you how replaci metal with plastic, where practical, can dramatically lower the weight and improve t performance of your robot. For demonstration purposes, we've chosen a steel alloy gear a asked our fabrication specialist Rick Hahn to make an identical gear out of plastic. It should remembered that in an already engineered and built robot, it may be totally inappropriate replace a high strength metal gear with a plastic one. Experiment to be sure your gear can sta the punishment. When building from scratch, if you find a metal gear that has the perfect si and ratios for your application but is overly strong and too weighty, a self-fabricated plastic ge may be just what the robot's doctor ordered.

Cast Your Own Plastic Gears To Lighten Up Your Robot



by Tom Durkin & Rick Hahn

photos by Iris Gilbert

Making identical plastic gear castings using a urethane rubber mold is actually easier than the injection method Rick Hahn used in the last issue of RS&T ("Inject Some Fantastic Plastic in Your Next Robot.")

Instead of the noxious, slow-drying Clear-Lite casting resin he used last time, Rick chose Quik-Cast polyurethane—a two-component, low-viscosity, fast-curing, and non-rising casting material that solidifies within 3-5 minutes. **Warning: follow safety directions as labeled on the products.**

Step 1: Clay in place

Here's how he did it:

1 Using a plastic box with vertical sides, lay a level, 1/2-inch bed of Plasticene modeling clay.

2 Place the metal gear on its flat side on the clay bed as illustrated.

3 Leave the small metal axle inside the gear. This will prevent the axle hole from filling up when you pour the molding material over the metal gear. The axle rod should protrude well above the end of the gear shaft so that it will become firmly embedded in the mold in a vertical line along the axis of each casting.

4 Spray the gear and clay bed with a release agent (WD-40 or Pol-Ease 2300). Make sure all the gear teeth are lightly coated to ensure that the gear will release easily from the mold without damaging it.

Step 2: Metal gear in place prior to pouring RTV rubber

5 Mix the A and B cans of RTV urethane rubber as instructed. Pour the liquid to cover the entire clay bed and the gear by at least 3/8 of an inch above the end of the axle protruding from the smaller gear.

6 Jiggle gently, if necessary, to level the liquid and help air bubbles rise to the surface.

7 Set the mold aside at room temperature for at least 24 hours.

8 When the mold has cured, remove the mold and clay from the box. Slide a thin metal blade around the edge of the box if necessary to loosen the mold.

Step 5: Pouring RTC rubber to form mold

9 Carefully separate the metal gear from the mold. Make sure no teeth are stuck to the mold, as this could damage it and make the mold useless for casting.

10 Drop the flat side of the mold back into the plastic box. The axle, embedded in the mold, should point straight up.

11 Spray the mold lightly with release agent. Especially make sure all the gear teeth impressions and the metal axle are coated.

12 Mix the two compounds from the Quik-Cast kit as instructed by the manufacturer. If you want a lighter weight gear, mix in several thousand microspheres—hollow glass spheres ranging in size from 20 microns to 200 microns.

13 Time is now of the essence. You have less than 30 seconds to make your casting. Pour the liquid plastic into the mold from the side so that the air will be pushed out of the deep gear shaft.

Step 14: Removing plastic gear

Wait five minutes for the casting to cure, then gently remove the casting from the mold. Do not dislodge the metal axle from the mold.

14 Compare the casting to the original metal gear. If the fit is perfect, go ahead and cast some more gears. If on the other hand, the fit is not perfect, break the mold and start over.

15 Always compare each casting with the original metal gear. If you begin to see imperfections in your castings, it's time to retire the mold.

16 We found there are at least two advantages plastic has over metal:

Weight

The most immediate and apparent advantage is the weight difference. Our steel gear weighed in at a hefty 1.7 oz. (48.2 grams). Rick's solid plastic replica graced the scale at a mere 0.3 oz. (8.5 grams). When Rick added a few thousand air-filled microspheres into the plastic mix, he got the weight down to a svelte 0.2 oz. (5.7 grams).

Many robot contests have upper size and weight limits. Dropping 1.4 oz off the drive train leaves all that much more for payload—or at least a better chance of squeezing under the limbo bar of the weight limits.

While running at constant speeds, you may not detect much difference in performance between metal and plastic gears. But, hey, let's deal with the real world of robots: A robot goes, stops, bumps into things, turns, reverses, speeds up, slows down—and generally does the herky-jerky until it sucks all the juice out of its power supply. Here's a no-brainer: Which robot's battery is going to be depleted first?

On a performance level, from zero to top speed, a plastic gear will beat a metal one off the line every time. It simply takes less—much less—torque to turn 0.2 oz of plastic than 1.7 oz of metal.

Furthermore, reversing the direction of a metal gear requires a much greater power drain from the battery, because it has to overcome the inertia of the metal gear. A robot with a plastic gear could already be going in the opposite direction before the bot with metal gear has even stopped.

Economy

Precision metal gears are often hard and/or expensive to come by. You may be lucky enough to find just one of the perfect size, but suppose you need three more identical gears? Using Rick's quick-and-easy mold-and-cast technique, you can make four identical gears, and still come in under the weight of a single metal one. Not only that, you can make spare gears, just in case.

These are just some of the apparent advantages of plastic over metal. However, as with everything else in life, there are trade-offs. In a future issue, we'll report how well plastic performs against metal when RS&T Labs puts the gears through a series of bench tests.

Materials

- Small plastic box, large enough to contain the metal gear with room to spare. Available in any craft store.
- Plasticene modeling clay. A 1x1x5-inch bar usually costs less than $1 in any craft store.
- One quart kit (two cans) of TAP Plastics RTV (room temperature vulcanizing) urethane rubber molding material —$22.15.
- Release spray: 13 oz. can of WD-40 (any hardware store) —$3.49 OR
- 14 oz. TAP Plastics Pol-Ease 2300 silicone spray – $12.60
- One quart kit (2 cans) of TAP Plastics polyurethane casting system – $16.95.
- Optional: one 4-oz. jar of TAP Plastics Microspheres – $5.30
- Disposable paper or plastic cups in 1-oz. and 4-oz. sizes. Available in craft stores and pharmacies.
- Disposable plastic or wooden stirrers.

To obtain a free 1998 TAP Plastics catalog write or call:
TAP Plastics Inc.
6475 Sierra Lane
Dublin, CA 94568
800.246.5055
If you choose to use products from other companies, make sure to follow the manufacturers' instructions.

Electric motors make things happen, without them our robots are ... NOT. Unfortunately, motors usually are not equipped to do anything but spin. So we need to gear them down to have them perform useful work. But not many of us have the time to build, or the cash to buy the necessary gearboxes. Fortunately, RS&T readers can convert a servo into a motor, complete with built-in gearbox. In this article, a natural follow-up to his "Digital Brain" articles (see RS&T, Premier and July), Karl details how to modify a servo, and then points us toward making a small mobile robot.

Motorize Your Small Bot by Modifying the Futaba Servomotor FP-S148

by Karl Lunt

photos by Iris Gilbert

If you can gather up these tools, you can modify the Futaba servo into a high torque drive motor for your hand-built robot.

After you've become familiar with using SBasic to program Motorola's 68HC11 microcontroller (see RS&T, Premier and July), you'll want to add motors to your robot. I've built a bunch of bots using the Futaba S148 hobby servo as a drive motor. These R/C motors normally go back and forth, and the car and airplane guys use them for controlling steering and lifting surfaces. But with a simple mechanical mod, you can make these motors go 'round and 'round. Their uniform shape, small size, high torque, and built-in drive electronics make them an ideal motor for beginners.

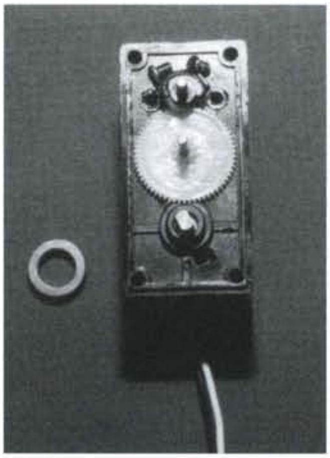
A modified S148 is an inexpensive, tough, long-lasting motor, with 42 oz-inches of torque. It should last about 100 operating hours, and top out at about 50 rpm. In fact, if you're using the 68HC11 mentioned above, you can control the speed from 0 to 50 rpm, although the control function is highly non-linear and is unique to each motor.

You can buy S148 servos at nearly any hobby store for less than twenty bucks. Also check out Tower Hobbies, one of the largest hobby mail-order stores in the business. They have great prices, a wonderful catalog, and very prompt delivery. Visit them at www.towerhobbies.com. And keep them in mind when you need any of those weird mechanical linkages or doodads; chances are the R/C crowd has already solved whatever problem you've stumbled over.

Here are my instructions for modifying a Futaba S148 servomotor for use as a robot motor. Read the instructions through carefully, and take your time as you are doing the mod. There isn't anything really difficult here, but you don't want to break a $15 motor by rushing.

IMPORTANT: If you intend to use a modified S148 with one of Marvin Green's BOTBoards, you MUST swap the red and black leads on the S148 motor. Marvin's board was designed for a different motor, so plugging in an S148 without reversing these leads would damage the motor! Carefully pry up the plastic retaining finger on the surface of the connector that holds the red lead in place. Lift this finger only enough to slide the red wire and its gold contact out of the connector shell. Do this same operation to free the black wire, then insert the wires back into the opposite holes. When done properly, the leads in your servo's connector should be in red-black-white order. I usually use a hot soldering iron to burn a large X into the connector's plastic shell, showing that I've modified the wiring for this motor.

In the following instructions, "front" means the part of the motor case that encloses the motor's output shaft (and has the Futaba label on it); "back" means the opposite side of the motor case.



The view during Steps 4, 6 & 7

You will need:

- Jeweler's screwdrivers (Phillips)
- Small solder iron
- Solder sucker
- Needle nose pliers
- Needle nose Vise Grips (6")
- Diagonal cutters
- Two 2.7kΩ 1/4-watt resistors (you could probably use 2.2 kΩ resistors in a pinch, perhaps RadioShack 271-1325)

1 If your servomotor already has some form of mechanical coupler device screwed onto the end of the output shaft, remove it.

2 Remove the four screws from the back of the case.

3 Remove the front and back covers.

Step 5. Cut the travel-limiting spur completely off the gear.

4 Remove nylon center (top) gear and nylon gears on output shaft and motor shaft. Try not to disturb or wipe off any of the white grease on the gears.

5 Using diagonal cutters, carefully trim and remove the nylon spur on the surface of the large output gear. This spur normally limits the servo's movement to an arc of about 270 degrees. Make sure you remove the spur completely. You must not leave any chunks of nylon that might prevent the output gear from rotating freely.

6 Pry off the bronze sintered bushing from the plastic hub around the potentiometer (pot) shaft.

7 Remove the two small screws on either side of the motor shaft.

8 Firmly press on the pot's shaft to push it back through the servo's case. This should push the pot and the printed circuit board (PCB) out the back of the case. If it does not release, use the Vise Grips as follows: Note that the PCB is notched at all four corners. Using needle-nosed Vise Grips, carefully position one jaw on a back corner of the case where it will not interfere with the PCB as it is pushed out by the

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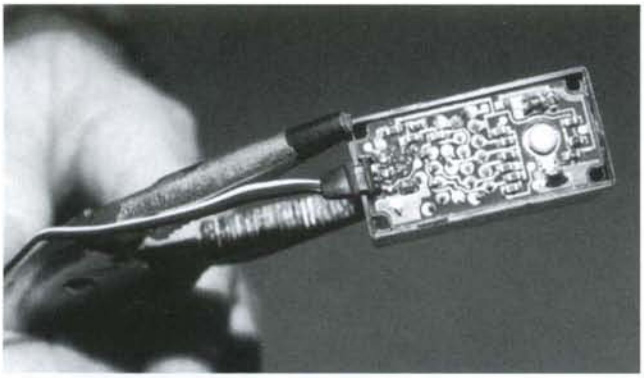
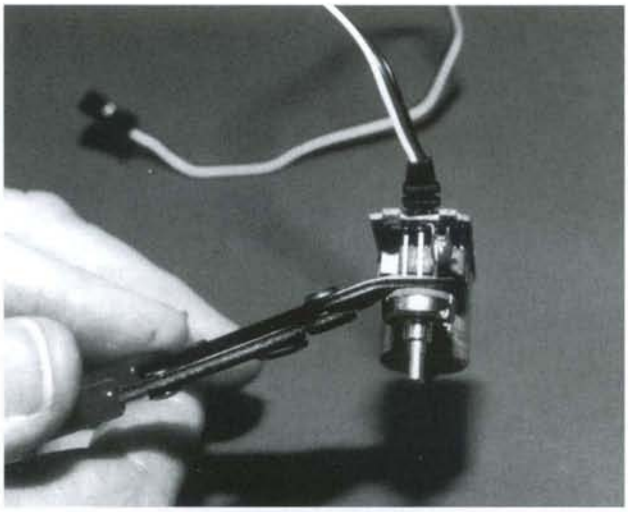


Performing Step 8. Firmly but gently, squeeze the shaft through the case.

other jaw that is on the pot shaft. A gentle but firm squeeze of the handles should free the PCB and motor.

WARNING: DO NOT pry on the PCB at all! DO NOT push on what appears to be the motor's spindle! It is a gear spindle only and is NOT attached to the motor

9 Remove the pot from the PCB by carefully heating its connections, then removing the excess solder with a solder sucker. Work carefully and do not damage the PCB's traces. If you are not interested in saving the pot, cut the pot leads at a convenient location and remove each lead individually.



Step 9. Cut the leads (or de-solder them).

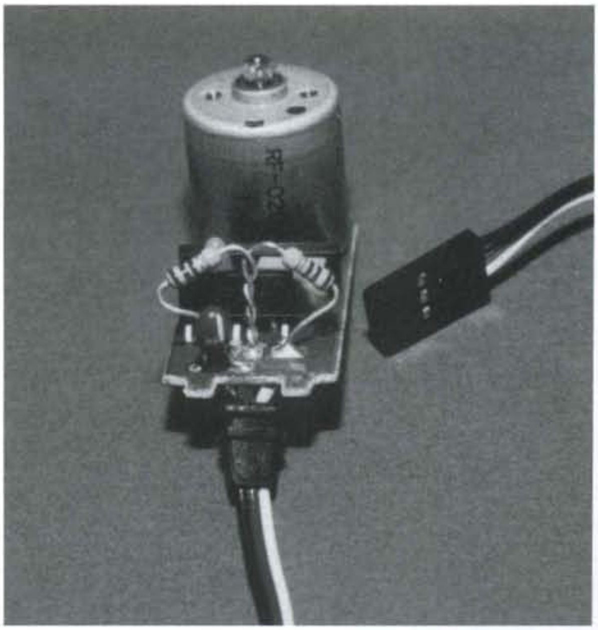
10 Install two 2.7kΩ resistors, wired in series, in place of the pot. The two resistors will appear to the servo's circuit as a 5k pot rotated to its center position. Refer to the photo at right.

Make sure you install the junction of the two resistors in the center pad on the PCB. If you discover that you can't insert two leads at once into the center position, here's an alternative technique: Rather than ream or drill out the hole, wind two leads (one from each resistor) tightly together, cut them cleanly, trim one of the leads back about 1/8", and straighten the remaining lead. Visually examine the resistors to insure they will fit inside the case when you later reassemble the motor. Insert the longer lead of the twisted two until the shorter bottoms out on the PCB and soldered both in place. The two remaining leads, having been previously bent and cut to a trial fit, should solder easily in place to complete the modification. Make sure you don't accidentally short any traces on the underside of the PCB when you solder the resistors in place.

11 Carefully reassemble the servomotor by reversing the steps above.

Controlling the Modified Servomotor

The 68HC11's timer subsystem makes it easy to control this modified hobby servomotor. Marvin Green laid out his BOTBoard so you can attach up to four of these motors, and my SBasic distribution file contains a library of code for making a motor go forward or backward and for controlling the motor's speed. Read the BOTBoard notes and my motor library software to see how little code is involved. As a rainy day project, spend some time with the 68HC11 Reference Manual (the "pink book") and figure out for yourself how the code works and how the 68HC11 timer subsystem supports these motors. You'll find it's time well spent, and you'll gain valuable insight into using this powerful subsystem.



Resistors installed during Step 10.

A Quick and Easy Mobile Base

We're nearly done now. Use a suitable base material, such as blank copper-clad printed circuit board stock or thin acrylic plastic, cut to about 5" square. Use some double-sided foam tape, available at most hobby stores, to attach two modified hobby servos to the underside of the base near the rear edge. Similarly, attach a RadioShack 4-cell AA battery holder to the top of the base near the center, along with the BOTBoard.

Note: If you use blank PCB stock for a base material, you should first lay down an insulating area of masking tape or duct tape where the BOTBoard will rest, to prevent shorting out any circuitry when you press the BOTBoard in place.

Drop by the local hardware store and pick up some large plastic furniture knobs, about $1 each. These make great front skids for small robots and, unlike casters, won't catch sideways and throw your robot off-course. Mount one of these skids to the underside of your robot base, near the front. Add a suitable wheel, such as a 2-3/4" Dave Brown Lite-Flite wheel, to each motor by fastening a wheel to one of the black plastic control horns that came with the servomotor. Once the wheel is bonded to the control horn, using hot-glue or small metal screws, you can fasten the wheel and horn assembly to the output shaft of the motor using the supplied black metal screw. Check Tower Hobbies or any other large hobby store for Lite-Flite or other suitable wheels.

There isn't anything magical about the dimensions or placement that I've just given you. Feel free to experiment with base material, base size, arrangement of components, wheel size, or just about any other element you like. The mechanical layout makes each robot unique, and lets you add your own creative mark. RS&T

Keep On Keepin' On.....Karl

Author **Karl Lunt** introduced readers to digital brains in RS&T's Premier and July editions using the 6811 processor and SBasic. He's a veteran robot programmer and a leader in the Seattle Robotics Society, perhaps the most helpful group in the U.S. He's written a hundred articles on home-built robotics, and he invented the SBasic programming language. His personal website, www.seanet.com/~karllunt, is one of the most informative places on Earth.

Karl's Suggested Resources

The Futaba FP-S148 Servo
available fromTower Hobbies
www.towerhobbies.com
and other well stocked hobby shops

Marvin Green's BOTBoard
available from Mondo-Tronics
800.374.5764
www.RobotStore.com
The BOTBoard documentation includes a full parts list with suggested suppliers.

Zorin's ModCom HC11 board
is available as a kit or ready to use.
206.282.6061
www.ZorinCo.com

The 68HC811e2 microcontroller chip
available from Arrow Electronics
47 Mall Dr, Commack, NY 55317
800.833.3557
www.arrow.com

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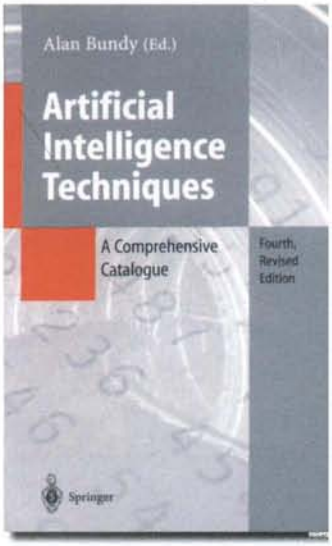

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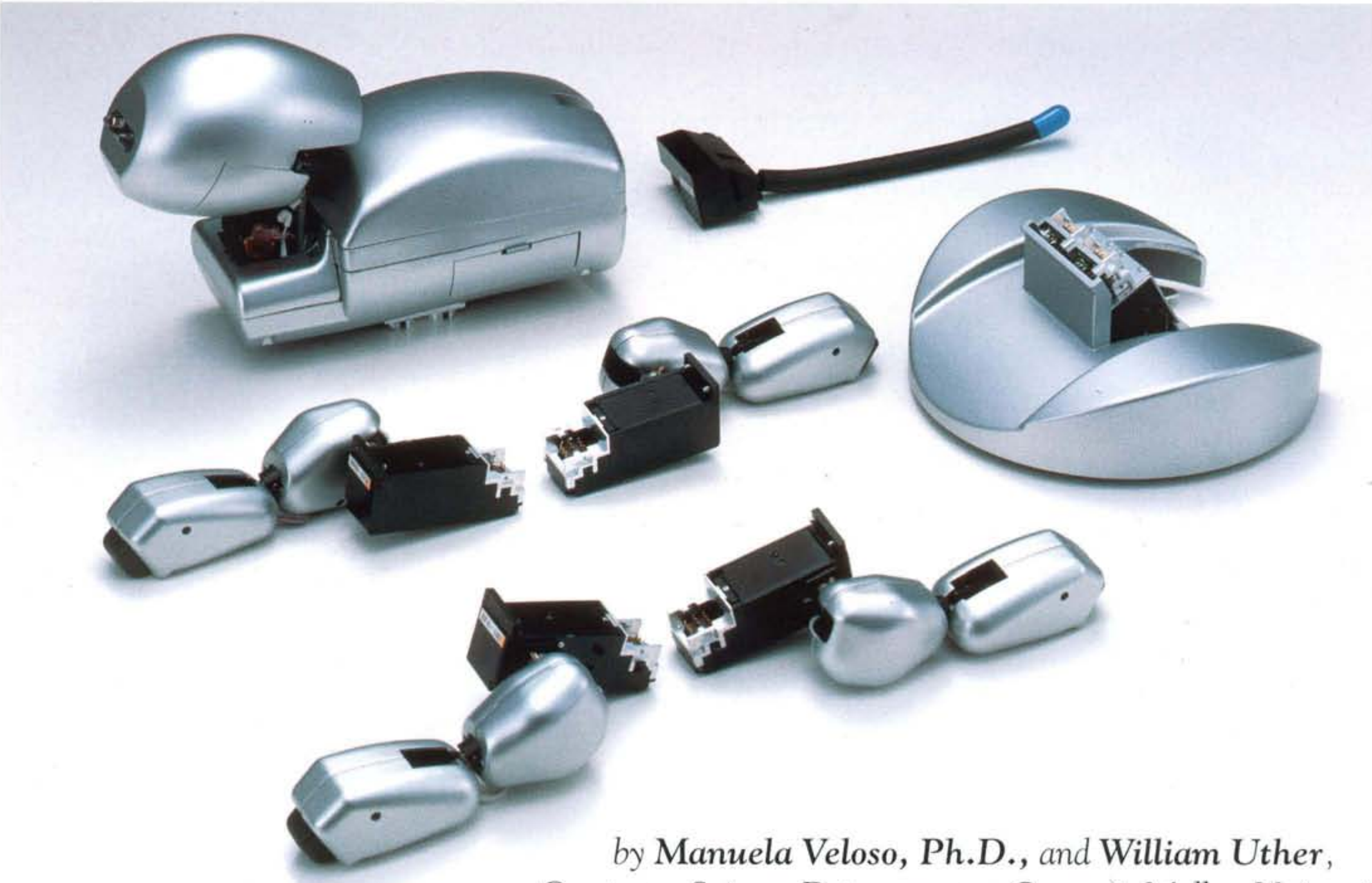
WALKING SOCCER-PLAYING ROBOTS



by **Manuela Veloso, Ph.D.,** and **William Uther**,
Computer Science Department at Carnegie Mellon University,
and **Masahiro Fujita**, *Sony Corporation.*

The Computer Science Department at Carnegie Mellon University (CMU), Pittsburgh, made a significant showing at the RoboCup'98 competitions. The games were held last July at La Cite des Sciences et de l'Industrie in Paris, France, coincident with the human World Cup soccer tournament. CMU competed in two leagues at RoboCup'98 and won both of them: the Simulation League, in which thirty-four teams participated, and the Small-size Robot League, in which 11 teams competed.

Another team, CMTrio , won the championship in the Legged Robot exhibition series, competing against teams from the University of Paris 6, and Osaka University. All three teams in the league were equipped with Sony Corporation's soccer-playing quadruped robots based on an entertainment, or pet-type platform. Each team fielded three robots and Sony helped prepare all three teams for the competition.

This feature article is about the CMTrio/Sony winning team and Sony's unique, innovative, fully autonomous robots. These bots feature an open architecture, a significant degree of hardware and software modularity, and memory card expandability.

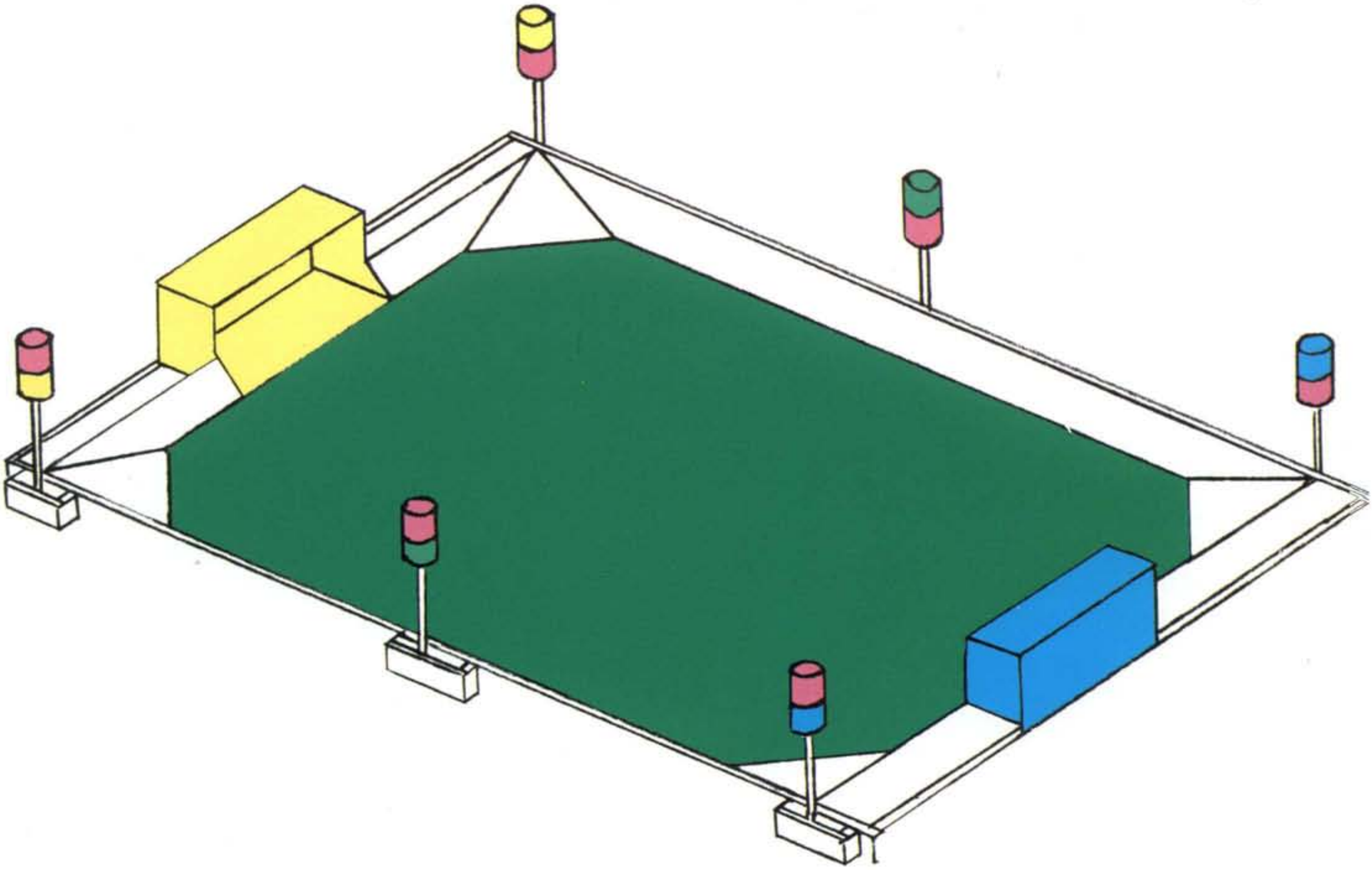


Figure 1: The RoboCup'98 Soccer Field for the Legged Robot Exhibition.

Robotic soccer represents a very challenging environment in which multiple robots, acting as teammates, work together to achieve concrete objectives in the presence of adversaries. Problem solving in this dynamic, complex environment requires that the robots learn from previous experience and feedback. To achieve this, CMU built into the robots learning, navigation, localization and role-based behavior capabilities that allowed them to operate as teams on a small soccer field. CMTrio strategy was accomplished by virtue of pre-defined behaviors.

The RoboCup'98 Setup

The legged, quadruped robot as a soccer player comprised a fully autonomous system without global vision or wireless remote operation. In addition, in order to simplify the exhibiton series, no modification of hardware by the three different competing teams was allowed. The Legged Robot Exhibition Match was therefore a software competition among three teams equipped with the same Sony platforms. Figure 1 shows the field for the legged robot exhibition match.

Team Composition. Each team had three players. This is the minimum number for team play, or collaboration tasks, one of the research objectives of RoboCup.

Color Environment. The important game items, the ball and the goals, are painted with different colors so that a standalone robot can process vision tasks in real time. Eight colors were chosen for game items and field landmarks so that a robot could easily distinguish among objects.

Field Size. The field size, 2 meters x 3 meters, provided enough space for six robots to navigate while dribbling and passing the ball.

Slanted Wall. The walls on all four sides of the field slant outward and upward at 45 degrees, with a triangular slanted wall in each corner. These walls effectively return the ball to the field when it is pushed against the border.

Landmarks. Six poles, located at the corners and along the sides at mid-field, provide landmarks for robot self-location. Each landmark is painted with two different colors so that six different poles can be painted with only four different colors. The robot measures the distance to two markers to compute its position on the field.

A Quadruped Legged Robot

Our robot soccer players used in the RoboCup exhibition match were based on Sony's OPEN-R architecture, proposed as a standard architecture for robot entertainment systems. The main advantage of this architecture is a high degree of modularity involving the use of hardware components, such as appendages that can be easily removed and replaced to change the shape and function of the robots, and modular software components that can be interchanged to modify behavior and movement patterns. The current configuration for Sony's entertainment robot is a small quadruped which can be changed into a rolling robot. It introduces an entirely new category of robot designed for entertainment uses. The modularity features of the OPEN-R architecture represent a significant improvement in robot design.

OPEN-R is based upon a decomposition technology for both hardware and software modules. This technology facilitates the building of different kinds of robots, such as legged, or wheel-based. It also provides for various software configurations. For software researchers, OPEN-R provides a highly reliable physical platform that frees them to concentrate on software development for a new image processing algorithm, posture control, agent architecture, and so on. Furthermore, they don't need to develop software from scratch, because OPEN-R now provides some software modules such as color detection and walking control. This means that OPEN-R can accumulate the developed software as reusable components, and accelerate autonomous robot research.

In addition, hardware researchers can design their own hardware modules with an OPEN-R interface, that can then be incorporated into an existing OPEN-R system. In RoboCup'98, modification of robot hardware was prohibited; however, in principle, it is possible to build different styles of robots with various sensors and actuators that have an OPEN-R interface.

Significant Features of OPEN-R Architecture

Interchangeable Hardware Modules for Various Physical Configurations. Through the use of interchangeable hardware modules, such as appendages (in this case—legs), it is possible to construct robots that can be reconfigured to suit multiple uses. For example, a 4-legged walking robot can be changed into a wheeled robot by disconnecting the hind legs and replacing them with a wheeled module. By employing an easily adaptable mechanical structure, hardware modules can be changed without the need for special tools.

Hardware-Related Data Transmission for Plug-and-Play Connectivity. Built into each hardware module is basic data that describes the module's structure, function, and position to enable it to be controlled by the robot. As each hardware module is attached to the robot, data is transmitted from the module to the Central Processor Unit (CPU) in the main body via high-speed serial bus. The data causes the robot to recognize the configuration of its entire body, its capabilities for movement, and its functions. The robot then uses the data to select the most appropriate control signals for coordinating movement and disseminates them to the individual appendages. It is not necessary to replace the software program that controls the robot's movements even when appendages are removed and replaced. Rather, it is possible to attach and remove the individual hardware modules with the ease of plug-and-play connectivity.

Interchangeable Software Modules for New Applications. The software programs that control the robot's movements and responses are also modular, and they are introduced into the CPU through card slots in the main body. Using pre-recorded modular memory cards, the robot's behavior is changed by simply replacing one memory card with another suited to a different purpose. In addition to software programs that would allow the robot to act as a pet or an opponent in a game, image and sound recognition programs can make it adaptable to a wide variety of other robot applications. This is accomplished by simply changing or replacing modular software.

OPEN-R Technical Summary

Operating System (OS):	Aperios (Proprietary real-time OS)
OPEN-R Bus	10 Pin Connector
• Data	2 Pin
Data Transmission Speed	12 Mbps
• Clock	1 Pin
Clock Frequency	12 MHz
• Circuit Power Source	3 Pin (including 1 ground)
Voltage/ Maximum Current	3.3V, 1A
• Mechanical Power Source	4 Pin (Including 1 ground)
Voltage/ Maximum Current	5V, 2A
Memory Card Interface:	Memory Card Specifications
Expansion Interface:	PC Card Specifications
Development System Interface:	USB Specifications

Please see Walking Robots, page 57

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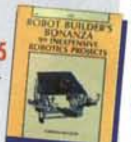

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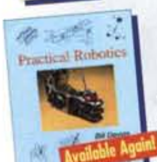

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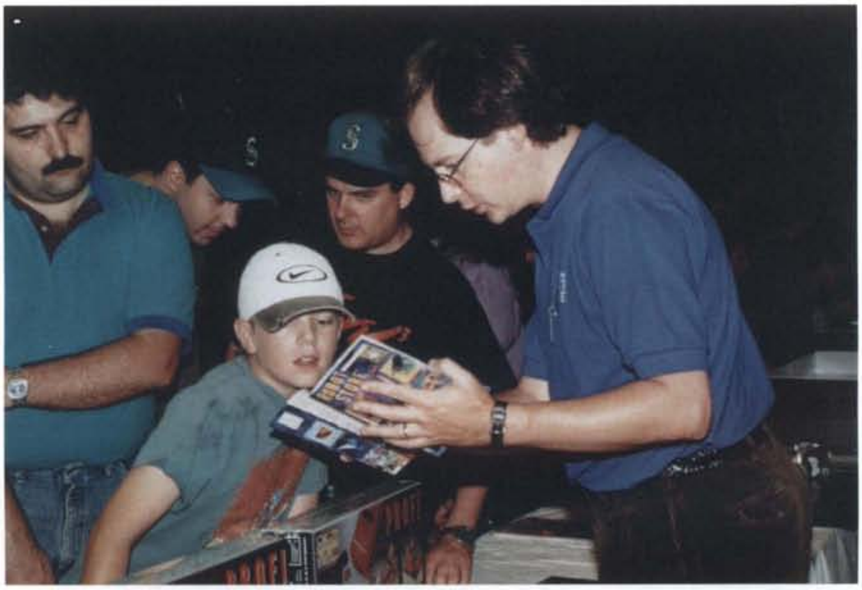
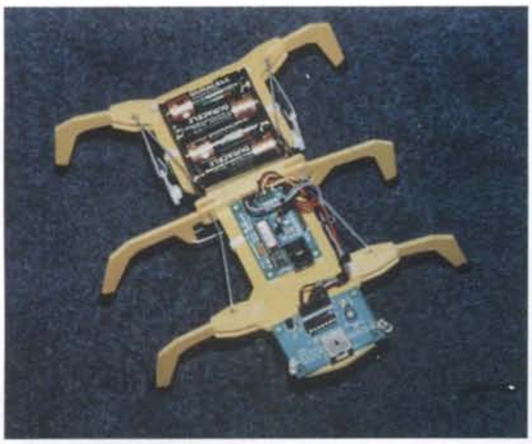


Mondo-Tronics' Roger Gilbertson introduces The Robot Store's fifteenth catalog to a soon-to-be robot builder.

Newton Research Labs' Mach V high-speed autonomous soccer robot.



Lynxmotion's Hexapod walker strutted for RoboExpo using the new First Step programmable microcontroller (introduced in July's RS&T).

Randy Carter with Victor, a cube-stacking robot designed for a contest at the University of Washington. See the website www.nwlink.com/~kevinro/uwcontest for details.

Newton Labs' John Bramblet shows a future roboticist how to attract and guide a robot with a color-coded paddle.

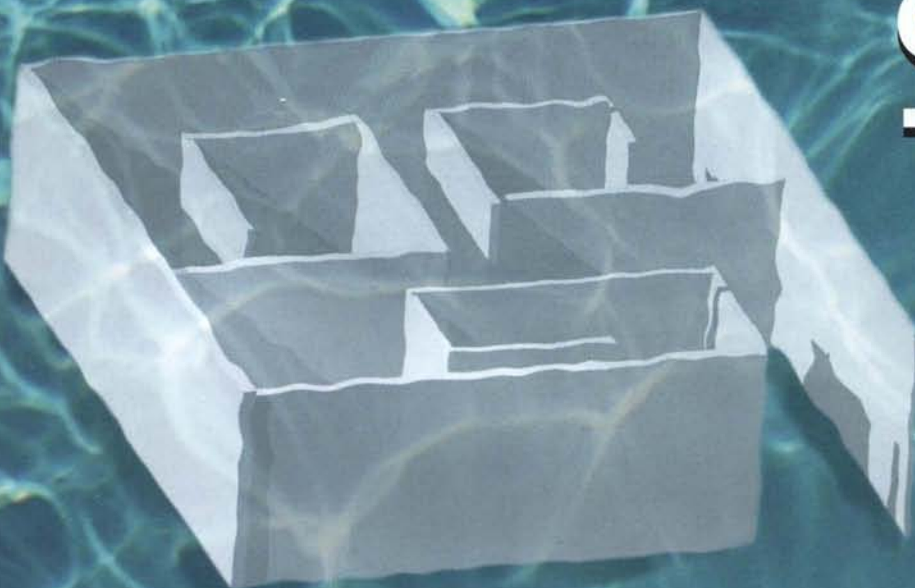
Left to right: Carl Witty, Jacob Parks, Randy Sargent, and Richard Everett, all part of the Newton Research Labs team.

Seattle Robotics Society's Garret Myrick, 13, and his four-legged walking bot.

RS&T

Popular Micromouse Algorithms, Part II

A Depth-First Search



By Tak Auyeung, Ph.D
University of California, Davis

The second 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. IEEE chapters organize competitions annually all over the U.S. 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. A micromouse robot does not know the configuration of the maze before its first run in the maze. The coordinate of the destination is, on the other hand, 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 to the destination. In the July 1998 issue, we explained the terminology used, basic robot abilities, and exploring the maze (pg. 31). 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, and if the island is its destination, it will fail. The failure is, of course, attributable to the inadequate algorithm. This article discusses another popular algorithm used to solve the micromouse maze—**Depth-first Search.**

Leave the wall to find your island.

This method is a little more complicated than the wall-hugging technique. That's the bad news—the good news is that it will explore, find and map our elusive island! Essential features of the depth-first search algorithm are that it:

(1) remembers which cells are already explored;
(2) systematically explores unexplored cells;
(3) goes back (retracts) when there are no unexplored but reachable cells.

Unlike the wall-hugging method, depth-first search (DFS) requires some supporting data structure. First, a "recursive" description of the depth-first search method.

```
DFS (coordinate X).
 Mark X as explored
 for all Y such that Y is an open
  neighbor of X
   if Y is not explored then
     move from X to Y
     DFS(Y)
     move from Y to X
   end if
 end for
end DFS
```

You may ask, how do we know whether a cell is an open neighbor? The robot knows because it senses the presence of walls in front, to the left and to the right of it. Furthermore, the robot also remembers walls that it has encountered.

Note that this algorithm does not stop at the destination (as there is no test for the destination in the code). This algorithm explores *all* cells reachable from the starting cell, then returns to the starting cell. The depth-first search of a cell is invoked simply by DFS(S), in which Cell S is the starting location.

Translating recursive to iterative–finally easy understanding

A recursive description is difficult to demonstrate, and a recursive function is difficult to implement (especially on a microcontroller without a deep stack). Fortunately, all recursive descriptions can be translated to non-recursive *iterative* descriptions. The only requirement to understand the iterative version of the depth-first search method is understanding the meaning of *stack*. A stack is a container where the last item put in (a "push") is the first item retrieved ("a pop"). This manner of inserting and retrieving information is also called "LIFO" for last-in-first-out. You may think of a stack as a pile of plates when you wash dishes. The last dish you place on the pile (push) is the first you wipe dry (pop). Like the top of the dish pile, the top of the stack is the item that will be the next item to be retrieved (popped).

With this in mind, let us recast the depth-first search method in an iterative style.

```
DFS
 empty stack
 push starting location S to the stack
 while the stack is not empty do
   let X be the location represented
    by the top of the stack
   mark X as explored
   if there is an unexplored open
    neighbor N of X
     push N on the stack
     move from X to N
   else
     pop the element representing
      location X from the stack
     if the stack is not empty
       let Z be the location
        represented by the top
        of the stack
       move from location X to
        location Z
     end if
   end if
 end while
end DFS
```

Stack Bottom Top	Explored Cells	Action and Explanation
S		Initialize the stack with just Cell S.
S	S	Mark Cell S as explored.
SA	S	Cell A is unexplored and an open neighbor of Cell S, "push" Cell A to the stack. Note that we choose Cell A instead of Cell C because we explore clockwise from the north. At this point, move the mouse physically to cell A.
SA	SA	Cell A is now top of the stack. Note that the mouse is also at cell A physically. Mark it as explored.
SAB	SA	Cell B is unexplored and an open neighbor of Cell A, "push" Cell B on the stack. Move the mouse physically to cell B.
SAB	SAB	• • • The following steps are similar to the step above.
SABE	SAB	• • •
SABE	SABE	• • •
SABEH	SABE	• • •
SABEH	SABEH	• • •
SABEHG	SABEH	• • •
SABEHG	SABEHG	• • •
SABEHGF	SABEHGF	At this point, the robot is at Cell F. Cell C is the only unexplored open neighbor of Cell F. The robot "pushes" Cell C on the stack, then moves to Cell C.
SABEHGFC	SABEHGF	The robot is now at Cell C.
SABEHGFC	SABEHGFC	The robot is at Cell C. Mark Cell C as explored. Note that at this point, Cell C has no unexplored open neighbors (both Cells S and F are marked explored). The "else" part of the conditional statement executes, and Cell C is "popped" from the stack. The robot moves to the new stack top, Cell F.
SABEHGF	SABEHGFC	The robot "backtracks" because the current cell (top of stack) has no unexplored open neighbors until further notice. At each step of retraction, the algorithm "pops" the stack and moves the robot to the new stack top.
SABEHG	SABEHGFC	• • •
SABEH	SABEHGFC	• • •
SABE	SABEHGFC	• • •
SAB	SABEHGFC	• • •
SA	SABEHGFC	The robot backtracks to Cell A. Of all open neighbors of Cell A, Cells S and B are explored, but Cell D remains unexplored. The "then" part of the conditional statement executes. The robot "pushes" Cell D on the stack and moves to it.
SAD	SABEHGFC	The robot is now at Cell D.
SAD	SABEHGFCD	The robot marks Cell D as explored. Cell D is also a dead-end (no unexplored open neighbors). The "else" part of the conditional statement executes. Cell D is "popped" from the stack, and the robot moves to Cell A.
SA	SABEHGFCD	Continue the back track, the robot "pops" Cell A from the stack and moves to Cell S.
S	SABEHGFCD	We are now back to the starting cell, Cell S.
	SABEHGFCD	EMPTY STACK–we are done!!

An Explanation–PLEASE !!

While the description looks complicated, we can easily demonstrate how the algorithm operates. Let us consider the following maze (Cell S is the starting cell and Cell D is the destination):

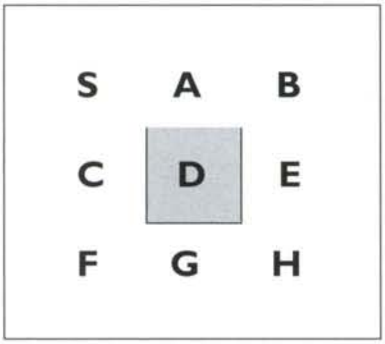


Figure 1: Coded layout of the maze.

We can trace how the stack changes as the algorithm executes. The first column of the **trace table** (previous page) shows the content of the stack (right-most item is the "top"). The second column indicates which cells are already marked explored. As an arbitrary convention, let us explore open neighbors in a clockwise fashion, starting with the north.

Note that the DFS method guarantees to explore all cells that can be reached from the start Cell S. By the end of the DFS exploration, the robot has a complete map of the maze. This fact is important when we need to find the shortest path from the starting cell to the destination cell.

You should now be more comfortable with the Depth-first Search method (especially the iterative version). The next article in this series will deal with—the Flood-fill 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.*

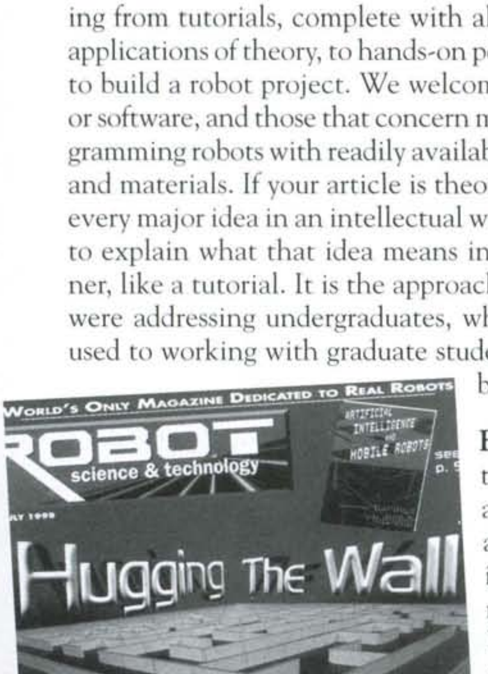
Submission Guide

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 educated to the highest level. A basic truth about all who read our magazine is that they 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 ranging from tutorials, complete with algorithms and practical applications of theory, to hands-on personal accounts of how to build a robot project. 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. It is the approach you would take if you were addressing undergraduates, when you were normally used to working with graduate students—the trick is to do both simultaneously.



Be Original. It is important that you be the author of your article and the purveyor of your ideas. If your unaltered material has already been published by someone else, we will not accept it, and this particularly includes information posted on the Internet. 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. You owe it to them, and to yourself, to keep the level of new content as high as possible.

Content

Your article should have at least introduction, discussion and conclusion sections. **Short articles** may contain 800 to about 3000 words, while the typical **feature** manuscript for RS&T should contain 3000-3500 words, and several photographs, figures, graphs or tables. Remember the essentials of good writing; clarity, conciseness and accuracy. A general outline:

Introduction. This is your opportunity to acquaint the reader with your subject matter with general information. It is a roadmap for the discussion that follows, and it should not be too precise.

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; it is your responsibility, and after all, your name will appear on the article.

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.

Double and triple check your facts. Verify the spelling of personal names, titles, and company names and make certain that dates, phone numbers, and references are correct.

If you use acronyms, do not assume that readers understand what they mean. The first reference should be fully described, followed by the acronym.

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

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

- Parts list.

- Known sources for obtaining parts, and be sure to include the complete address, phone number, website URL and e-mail address so our readers can contact the source directly.

- Any special equipment needed for construction or testing.

Photographs

At least two 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; a busy background detracts from the intended object of attention.

Focus—Depth of field and detail are vital. Do not send photographs that are out of focus since they will not be used. It should be noted that cameras that focus automatically often produce fuzzy images in the hands of an inexperienced photographer.

Include the whole subject in the photograph. If in doubt, shoot wide and we will crop it.

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 for 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:

Editor
Robot Science & Technology
2351 Sunset Boulevard, #170-253
Rocklin, CA 95765
USA

RS&T

Feedback Loop

"The technology is nearly available. There are probably a hundred thousand people worldwide who would be willing to pay $100,000 for [a household robot like C3PO]. That $10 Billion market will not go overlooked for long."

— Nicholas Negroponte, *Being Digital*, 1995.

The Potential For Analog Circuitry Is Alive and Well

I would like to comment on the Iconoclast's "Software Viagra" in the most recent issue of RS&T. I agree with what was said in that article. In fact, I go much further. Programmers are not only attempting to solve hardware problems with software, but they also attempt to solve everything else with the robot's brain. When we humans balance, we don't "think" about it nearly as much as we "react" to it. A robot should employ as much analog circuitry as possible to react to its environment and leave the software for solving other tasks. As an example, anyone attempting to balance a bipedal robot using software is indeed using a hammer to solve the problem. I would like to see some articles based on this type of non-software control circuitry (I'm not talking about simple bumper switches here, but "smart" analog circuits). Is there anyone in the field of robotics who uses these methods?
— James Ross

The Iconoclast responds:

Thanks for your comments and compliments. You make a good point - why not use smart analog circuits for reactive control? My guess is that; (1) many people find analog circuitry more difficult than digital design, (2) one can tune or fiddle with a digital approach by software mods, whereas changing an analog circuit means changing components, (3) many people come to robotics from a computer science background, and (4) computers offer the promise of versatility via programming. Although there's a price to pay in terms of complexity, cost and response time, computer control seems to be vastly preferred, relegating the problem to better, faster, cheaper computing power. The revolutionary change Rodney Brooks at MIT made to robotics in the late '80s was using tight feedback loops between sensors and actuators to achieve real-time response in mobile robots. This technique later came to be called "reactive behavior" and is used widely today for "low-level" control of mobile robots. However, analog circuitry is still a viable option that seems to have been slighted. The major proponent of analog circuitry is Mark Tilden, founder of the BEAM robotics approach. There is a BEAM web page at http://sst.lanl.gov/robot/.

Hang On Loopy, Loopy Hang On

Perhaps I'm missing something, or I'm confusing your algorithm, but it appears to me the robot will simply go into a loop of right turns if not placed with the wall to its right. It also appears you need to indent your loops and **if** statements or provide brackets. It is not obvious if the last **else** goes with the first or second **if** statement. — Theron Wierenga

Author Tak Auyeng responds:

Our reader is right on both counts! Good catches, however, the behavior of a wall hugger is not defined when there is no wall around. The logical choice, I guess, is to go straight forward until a wall is found. As for the indentation, it must have been lost in the editing. We have made certain that the depth-first search algorithms are properly indented in the article on page 40 of this issue.

The editor adds:

One of our goals is to have no mistakes in the magazine, and we are working hard toward that. We feel that we have made significant progress with this issue, and would like to know what you think.

Robots Aren't The Only Things That Have To Be Balanced

Just a quick note having read RS&T issue two. I found the articles a little short. For example, I wanted to read more about the bridge-climbing winners and the micromousers. It seems you put so many different things in this issue that there was not room for them all to be covered properly. A web link does not satisfy when you cannot click on it while reading the magazine. Other subjects are treated better. I would say that there was too much of the basics, since you had both Flashy Logic (5 pages) and Basics of a Digital Brain (5 pages). But then, as someone who has built electronic hardware and programmed micros for over 20 years, maybe I am biased. Please consider covering fewer topics with more detail, and be assured I look forward to my next issue.
— Ian Cull

The publisher responds:

Thanks for the feedback, Ian, and I agree with every bit of it. I was also disappointed to see so few technical details emerge from our bridge-climber and micromouse stories. So I trimmed the fat, *cut them down, and expanded Flashy Logic with useful information. I think you will find that this issue is more technically in-depth, but that it also continues with our policy of imparting how-to knowledge to our readers who are not as experienced as you are. Our desire is to strike a balance between very technical features and the basics, so that we present something of interest to all our readers. Please continue to let us know how we're doing.*

There Are Some Centerfolds Your Mom Can See

Great issue again, so don't drift from this format, which has something for everyone. Keep up the beginner's focus. Only one complaint: Please put advertisements on the back of the centerfold. I keep all my old magazines for reference and would like to hang up the centerfold, but it takes content away from the magazine. — Rick Rowland

Dear Rick,

Good point, and we have taken it to heart. But you know what? A fact of life in the magazine business is that no book can survive on subscriptions alone; advertising tends to pay the freight. The bottom line is that we have to keep you and our advertisers happy. Our solution is a compromise: We have, in this issue, set the standard for the centerfold by placing our own ad and a topical editorial piece on the back sides of the centerfold, along with a brief description of the subject portrayed. Let us know what you think.

Want To Get Wired? Help Is On The Way

Just wanted to drop you a note to thank you for your magazine. It's terrific, and even the ads are good. I never knew there was so much out there for personal robotics, and especially appreciated your TuteBot and Flashy Logic articles. I've always wanted to get into building actual robots, and while I'm good at whipping up mechanisms and devices, I just don't know enough about electronics to actually wire together a real robot. I hope you continue to run more intro-level articles as well as mid-ranged and advanced. — PAL

Dear PAL,

Thanks for the kudos, and you have put your finger on a key element of our editorial philosophy, which is to balance the content of our magazine with something for everyone. Thanks again and please stay tuned.

Doctor 'Dozer To The Rescue

First off, I just want to say that this mag is really cool. I've always been fascinated with robots and other motorized gadgets. I've been in the Navy for 7 years working with computers and after reading the premier collector's issue and the July issue, I now know more about programming than any Navy school ever taught me.

I have a question about the TuteBot article in the July issue. Dr. Bob Brady mentions a model bulldozer kit for the hacker version of the bot. There is only a small toy store in my area and they don't have much, and I only see one bulldozer lego kit in any of the web pages I've visited. Is the bulldozer model he talks about a lego or other set? I don't want to order the lego bulldozer and find that it is just one of the simple kid kits. I really want to try this out so any help is appreciated.
— Travis

Dear Travis,

One of our habits is taking care of hands-on robotics folks like you, so standby sailor, plan of the day follows: ***Mondo-Tronics Robot Store, www.robotstore.com, 800.374.5764,*** *has an excellent hackable bulldozer kit for about 40 bucks. It has a tank-like base, and a wired remote control for full forward, reverse, and left and right motion. The kit includes a twin motor gearbox, extra track segments and other parts, and runs on AA or D batts. Travis—check it out!*

Fabricators Unite!

I think your magazine is one of the best sources of information on the topic of robotics. I'm a software engineer by profession, but I like to play around with robotics. I have a little experience in electronics and restore pinball machines as a hobby. I especially liked the article in the most recent issue about injection molding small plastic pieces. It was one of those rare articles that could be just the key for someone building a robot. Looking forward to the next issue.
— David Wagner

Dear Dave,

Thanks, and you will notice that we continue the fabrication series in this issue with a feature on casting lightweight plastic gears. Toward the end of 1999, we will collect all these features and publish them in book form. It will be available through our Web site, www.robotmag.com.

WE'D LOVE TO READ YOUR FEEDBACK, WHETHER IT'S POSITIVE OR NEGATIVE.

Send
Correspondence to:
Robot Science & Technology
2351 Sunset Blvd #170-253 Rocklin, CA 95765
OR editor@robotmag.com

Newest Members to the RS&T Team

Publisher's Note: To make this a truly world-class magazine, and to make monthly deadlines, we sorely needed experience. We're incredibly fortunate that these folks are lending their expertise and energy to our endeavor.

—Mike

Floyd Painter
Editor-In-Chief

Floyd brings to our staff a dual background in microwave electronics and publishing. Following his Navy service as commander of a strategic communications squadron, he was a marketing engineer with Watkins-Johnson in San Jose, specializing in electronic surveillance systems. He later served as Editor-in-Chief of *The International Countermeasures Handbook* and *The C3I Handbook* at EW Communication in Silicon Valley. Most recently he was operations officer at Inkode Government Systems, which designs and builds radio frequency anti-counterfeiting systems. RS&T readers may know him as the Editor-in-Chief of the respected *Defense Electronics* magazine.

Gene Ronan
Technical Editor

RS&T extends a hearty 'welcome aboard' to our new Technical Editor, Gene Ronan. He joins us following a technical / editorial career as Senior Manager of Programs with Gencorp-Aerojet in Sacramento. He spent many hours working closely with senior scientists, investigators, engineers and technicians, editing technical reports and proposals. This followed his tenure with Electro Static Sounds Systems, where he progressed from writing manufacturing procedures to heading Information Systems. His expertise in technical editing will be evident as RS&T's technical accuracy and clarity approach infinity and beyond.

Patricia Delaney-Rios
Customer Service Representative

Pat added her valuable skills to our overworked Circulation, Subscriber and Fulfillment section. She came to us after 15 years of service as an Air Force supply officer. She earned a BS in Retail Management, and an MS from the Air Force Institute of Technology. She's got a heavy workload; but she makes it look easy.

Photographs of Floyd Painter, Gene Ronan and Mike Greene (pg. 5) by Cynthia Morrissey, Full Spectrum Photography.

Subscriptions & Renewals

Readers Note: More than ever, RS&T's direction is leaning heavily toward practical education at the individual level. I'd love to read your comments about this. Email Feedback@RobotMag.com or Robot Science & Technology 2351 Sunset Blvd #170-253, Rocklin CA 95765. —Mike

CHARTER SUBSCRIBERS (paid by Dec 1) may extend their subscriptions by choosing either:
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Don't miss a single issue! Send check or money order to arrive by December 1, 1998. Mail to: Accounting, Robot Science & Technology, 2351 Sunset Blvd #170-253, Rocklin CA 95765.

Visa and MasterCard accepted world-wide through our Secure Server at www.RobotMag.com or call 916-660-0482 for credit card orders, 9 a.m. to 5 p.m., California time, Monday - Friday.

NEW SUBSCRIBERS (starting November 1, 1998) will receive 12 issues for $39 (USA) *Pre-paid* Subscribers will be eligible for future special offers. Subscribers *outside* US *must* pre-pay. See International Postal Cost Notes below.

For our Special Canadian Friends: Renew, prepaid, before Jan 1, 1999 for 12 more issues, for only $49 (US funds to the Accounting address, just above). MasterCard/Visa see above.

Libraries and Schools: Robot Science & Technology is an exciting, informative magazine about an exhilarating and educationally vital topic, and it will prove to be one of the most popular periodical titles on your bookshelves. Act now to make this practical technology magazine available to your students, researchers, engineers and educators. They will thank you for it.
For $99 (in the US only), schools and libraries will receive 12 monthly issues of the magazine. Prorate for 36, 10 or 9 month periods. Specify the date you wish to begin the subscription. Send a prepaid purchase order or request a pro forma invoice.

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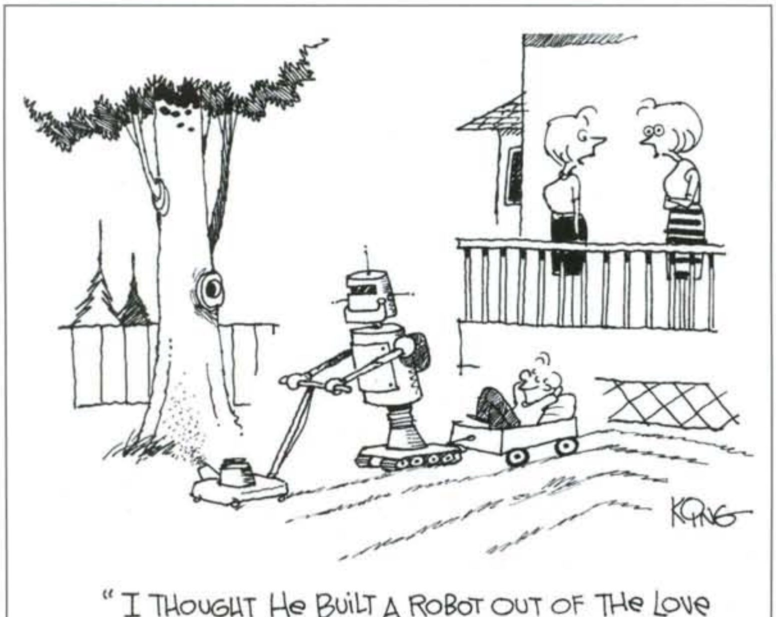
International Postal Cost Notes
(Most of the cost of international services is to pay shipping.)
International orders must be prepaid in US funds, check or money order.
International Subscriptions: 12 issues (individual or institution): $99 *prepaid.*

Subscriptions are risk-free! Full 90-day refund guaranteed in US and Canada. International refunds are prorated: see International Postal Cost Notes above.

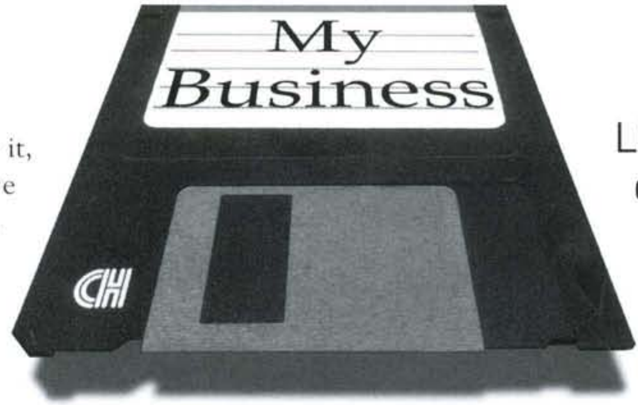


"I THOUGHT HE BUILT A ROBOT OUT OF THE LOVE OF SCIENCE. BUT NOW I KNOW HE'S JUST LAZY."

Booting Up Your Small Robotics Business

Your cornerstone order

by John Bassett



Willy Loman didn't say it, but he would have agreed: In business, nothing happens without a sale.

It's often painful for inventors to admit, but the most innovative products aren't always the greatest commercial successes. (Think about Beta VCR's and Macintosh computers, for instance.) More often than not, the product that is sold best tops the one that is designed best.

Our pal PropTop isn't much interested in emulating Willy Loman's "smile and a shoeshine" way of life. (Besides, howinhell do you shine a pair of sneakers?) Still, if he wants to make something of his robotics business, he must consider the sales side.

A sale to a major customer gives a company the cash to move its products into the mainstream.

When you peel away the layers of protective pomposity from most successful companies, you discover that most of them attained critical mass with a single sale, a sale of a key product to a major customer. That "cornerstone sale" gives a company the cash flow, prestige, and challenge to become a market force and move its products into the mainstream.

It won't be any different in the robotics business. During the next decade, thousands of companies in hundreds of industries will evaluate robotics applications for their manufacturing and security needs. The robotics businesses that will be listed in the Inc. Magazine 500 of 2009 will be the ones that anticipated the market, discovered the needs, and communicated their capabilities.

PropTop knows he can develop robots that will improve operations in many industries. How can he turn this into product orders? There are many steps, but these are critical:

Listen to your customers

Don't tell them what the robots you're making today do, ask them what operations they need robots to perform. Then adapt or design your product to fit your customers' needs.

Think outside the lines

That robot you built for fire protection might be more in demand as a sprayer of pesticides covering 100 percent of a floor surface each night.

Tell the world about your successes

Three hundred years ago, someone said "If you build a better mousetrap, the world will beat a path to your door." That was true then, when there were only a few significant new inventions each year. Today, in the time it's taken you to read this, dozens of great new products have been born. Don't assume that because ten companies in the computer industry know about your product that everyone else does. Send press releases and success stories to Robot Science & Technology and to trade publications covering the industry you sell to and all the industries you'd like to sell to.

Many inventors are shy, introverted people. They're not comfortable selling. The truth is, we're always being called upon to sell ourselves, to our teachers, love interests, bosses, and so on. In a fresh new industry such as robotics, you and PropTop are not really selling, you're teaching, giving out and receiving information that will help you and your cornerstone customer work together to solve problems for your mutual profit.

As Henry Kaiser said, "Find a need and fill it." Then tell the world about it, over and over. RS&T

How to Construct a Robot Warrior Part 1

by Ronni Katz

If you are thinking about entering a robotic warrior competition, here are some very useful tips on how to prepare. I have competed in the past two Robot Wars™ and will have three different designs to enter the next competition. For this article, I will be using my lightweight design "Chew Toy" as the example model. Of the three possible entries, this one is the most basic and the one that will actually be a "garage built" robot using easily obtainable parts and tools that most builders either already own or can acquire with ease.

For this first part, I will be covering the research and conception stage and the pre-construction phase. The latter phase is what you do short of cutting the metal and welding it together, etc. The steps I am detailing are what my team did in building our main entry, SPIKE (now up to Revision 3), and what are good ways for novice competitors to break in without getting in over their heads.

In conclusion, I will also be giving a partial listing of reliable part suppliers. It would be an article in and of itself to detail all the companies I know of that have supplied robot warriors with parts for their machines.

Step 1—Research

If your introduction to Robot Wars™ was what you caught on Sci-Fi Buzz or the Discovery Channel, there is much more you need to know before building Mass Carnage, your heavyweight entry. First, it is a good idea to see what the current Robot Wars Rules are *before* you design your entry. The rules do change slightly from year to year, although some safety parameters have remained consistent since the beginning. The rules against flames, explosives, corrosives and pyrotechnic devices on robots have been there from the start. However, newly added are the rules prohibiting wet-cell lead-acid batteries and that all robots have an easily accessible on/off switch. These changes, and others, were added for the 1997 competition and will no doubt be in effect at future competitions. There are many "unofficial" sites where robot builders can get information on robotic design, competition and building tips. The BEST place right now is the Robot Wars forum on Delphi whose Uniform Resource Locator (URL) is http://www.delphi.com/robotwars/. From this site you can learn about the SORC—Society of Robotic Combat — and other tidbits fledgling designers would find MOST helpful.

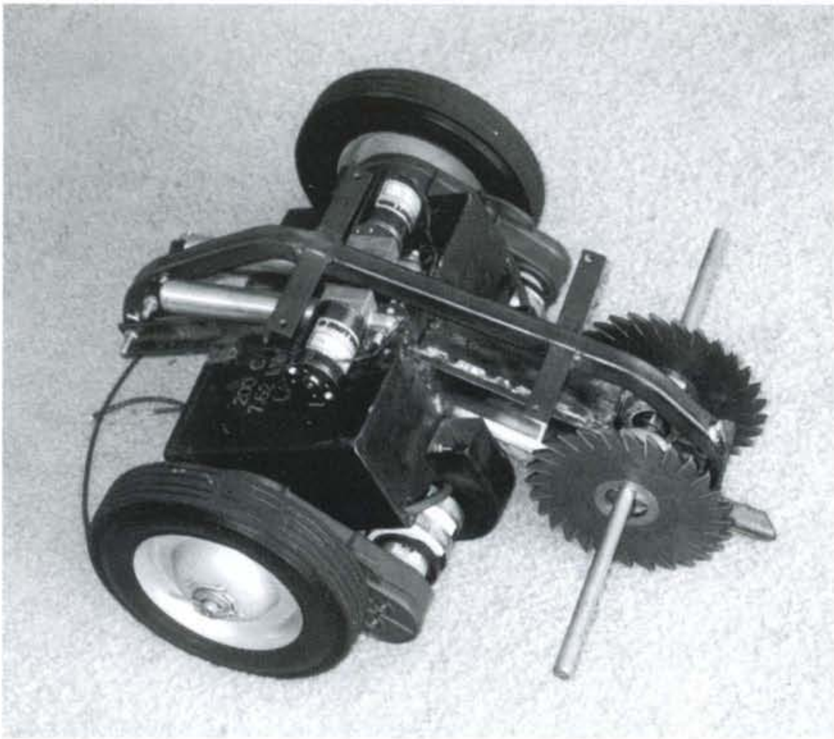
Another important researching tip is to determine what engineering efforts worked in the past and what efforts didn't. This can be accomplished by purchasing the videotapes offered for sale on the official Robot Wars site, the URL is www.robotwars.com, but if they no longer list this information, you can obtain it by request through their e-mail address: Robotwars@aol.com. They also maintain a "snail mail" address for those not net attached. It is Robot Wars, PO BOX 936, Fairfax, CA 94978 and you can get entry information by requesting it and enclosing a stamped self addressed business-sized envelope. The other way is to visit the unofficial sites owned and run by past competitors, like mine. Often posted on these sites is information on past entries, what worked and what didn't and why, and photos from the competition.

Videos are more than just Action-Packed

The tapes sold by the official site are highlights of the competition and are very glitzy with excellent production values. They are also about a half-hour long and focus mostly on the heavyweights. If you are building a heavyweight, this information might be enough. Since most new entries tend to be in the other weight categories, you may want to look at other video sources or written reports of what happened in the arena. Some past competitors shot video of their robots in action, or of the competition itself, and have been trading these home made tapes with other enthusiasts. The quality may not compare with professional videos but the information they contain could be invaluable. Most of those I've seen give you an idea of how the robots did in combat, what the arena is like, and other useful bits of data.

It is worth sending an e-mail to an online competitor to see if they have video or other information they would be willing to share with a newcomer. Most of the folks are very open and encourage those interested in participating in Robot Wars to discuss ideas and ask us more experienced folks questions. We old-timers want to see more people involved and are willing to offer advice. We can provide the names of reliable suppliers, where to get good quality remote control (RC) radios and speed controllers, and do design critiques (if you really need that kind of help) for the first-time competitor. I have links from my Website (www.cybercomm.net/~alindsey) to the sites of all past Robot Warriors on the Web. All the sites have something of value to offer.

Since I mentioned my Website, here is what I have on it. It has a photo of every entry in every weight class (over 200 photos) of robots from the 1996-97 competition and detailed reports of their battles. The site is currently being updated to include digitized video clips from the 1997 competition, as



ChewToy with protective armor removed.

robot parts are just exotic enough that the average hobby, electronics or hardware store won't carry them but a catalog company will. If you have access to a university library, especially at a school that has an engineering program, chances are it will have periodicals and books that may be of use.

Most of my research was via the Internet, telephone, in person and e-mail. Since many of the competitors are online, find an inexpensive Internet Service Provider (ISP) and get an account. The Internet is so mainstream that I found the ISP I am using listed in the phone book. Sometimes the local Internet service providers offer better rates than the larger national chains but, if you travel and need to connect while on the road, then a local ISP might not be the best bet. There are providers with wide areas of coverage, such as Erols (my current ISP) that give good rates and offer a variety of services. Since the Net is "where it's at" these days, getting connected is worth investigating.

well as new photos of the 1997 entries and their battle reports. By the time you read this, all the new stuff will be on my website and you can get it there. I included links to MANY sites connected to robot building and teams that have competed in the past. By the time this article is published, the four hour documentary on robotic combat teams filmed as part of a non-profit educational venture to promote the sport to schools and universities nationwide will be available to the general public. My Website has all the information on how to get yourself a copy.

Research is more than important—it is vital.

A good site to get information about Robot Wars and robotics in general is the Usenet newsgroup comp.robotics.misc. Here folks share facts about robots that they are building, where to find parts, Dremel tool techniques, etc. It is a good general discussion page and a good source of information. Many competitors subscribe to this newsgroup and often discuss their works-in-progress here. It is also a good place to ask questions when you have a construction problem. You can get advice on what type of motor would best power your heavyweight entry, Mass Carnage.

Outside of the Internet, other good sources of information are magazines like RS&T and hobbyist magazines that deal with RC and similar electronics. Ordering the parts catalogs seen in these publications can be extremely useful. Some

Research what supplies you have on hand to do your building. Do you own a Dremel tool? Do you have space in which to build or have access to a place to do the construction and testing? Do you have access to a machine shop or know someone who does? How about milling equipment? Checking out the availability of time on the milling machine in your friend's garage, or the willingness of the local metal shop to cut aluminum or steel to your specifications, will indicate what resources will be there when you need them. Local machine shops might find Robot Wars something they might want to involve themselves in and you might wind up with a sponsor. That happened with Spike II. The machine shop that did all the aluminum cutting and welding donated a portion of their services in exchange for advertising and help redesigning a PCB. Yes, barter still exists today. If you have skills to trade for time on that milling machine or access to the Heliarc welder, then go for it. It cut down on the expense of building our robot and we made new friends and contacts.

It definitely pays to look into the technical expertise that exists in your own neighborhood. RadioShack can supply electronic bits and pieces at a decent price. Investigating what equipment—specifically RC parts—your local hobby store can get for you is important. Hobby stores that cater to model makers (especially model makers who build their own RC planes, boats, etc.) often have a good selection of speed controllers and other essential equipment. Be sure you purchase a speed controller that will handle the current you intend to pump through it. Many people at the 1996 competition fried their speed controllers because they didn't check this detail. As far as RC equipment goes my advice is this: Don't get a cheap radio. It pays to invest in a good quality PCM or FM aircraft radio. The aggravation saved will be well worth the money spent. Trust me.

Step2—Conception

Once you've done all your research, gotten those parts catalogs, know the rules, and are sure of the weight class you want to be in, the next phase is coming up with the design sketch. You don't need AutoCAD or any heavy duty engineering software to create a basic design sketch. Our work was done in an artist's sketchpad and on notebook paper. The average builder won't have AutoCAD on his home PC (unless he is lucky enough to work somewhere that requires it or he has THAT much disposable income). AutoCAD isn't necessary if you are doing a simple basic design.

The photographs of my lightweight entry "Chew Toy" show how very simple the design is! Chewie is a very basic robot—all the essential parts, such as the motors, batteries, major weapons, etc., were not that hard to lay out and assemble. The robot's conception came out of the hypothesis "If I could only use the **Surplus Center** catalog to get parts to build my robot, then what would I design?" In reality, I have a lot more sources for parts. However, I was curious. Could I come up with an effective design by pretending I was limited in parts availability?

As you can see, "Chew Toy" has a very simple structure. It will rely heavily on its 3.5hp four-stroke motor and those rather evil sharp saws to do its battle damage. The body frame—the square steel tubing and the wire mesh that will be used for the armor—will come from Home Depot, another great inexpensive supplier. "Chew Toy" is also going to be something that all designers like—a cheap entry. The cost for this robot (everything BUT the speed controller) will be about $500. (Instead of doing what I had initially conceived—a simple relay system—I went out and "splurged" on a Vantec speed controller for "Chew Toy." Its cost was about what the ENTIRE rest of the robot cost but, because the speed controller is an item that can be reused in future designs, I looked at my extravagance as an investment. In addition, it saved the time that it would have taken to construct and properly test the relay system I had devised in the early phase of "Chew Toy's" development.)

Once you figure out what you want to build, the next step is building the mockup. What I do is cut out of balsa wood the frame and the parts into which the motor, the drive train, weapons system, etc. will be fit. Balsa is easy to work and any hobbyist who has done original model designs of airplanes, boats or the like has probably done mockups in balsa wood. Balsa wood is also cheap and readily available. If you botch something in the mockup phase, you can redo it much more easily than if you were working in metal.

Once you get your balsa wood mockup within your parameters and everything looks workable, you are ready to spec out your final project. The balsa wood project was then broken down into the component parts and used as guides for cutting the metal for the final project. If you are doing your own metal cutting, you can take your mockup apart and use each piece as a template for your metal pieces. I laid the pieces on top of the metal, traced the shape onto the metal, and then cut out the shapes. That way I was sure all the metal shapes would be the exact size I specified and, when cut and fit together, would replicate the mockup. Metal shops can also use your balsa template as a guide. If they are also going to be doing all your welding, it is a good idea to give them your design sketch and review it with them so they understand exactly what you want your finished piece to look like. Showing them the balsa mockup before you disassemble it for template parts is also useful, especially if you are working with people who have no prior experience with robotics.

In **Part 2** of this series, the actual construction of a robot, as well as testing to make sure the design on paper matches actual performance, and ways to ready it for the arena will be covered.

Parts Suppliers—Part 1

Industrial Motors

Most industrial motors are purchased through surplus dealers rather than direct from the manufacturer. Many people used these types of motors at robotic combat competitions.

Litton Poly-Scientific
1213 North Main Street
Blacksburg, VA 24060-3100
800.336.2112
www.litton-ps.com

Litton manufactures Clifton Precision industrial servomotors. These are well made high power and efficient drive motors. This brand is used on SPIKE II.

Pittman Motors
343 Godshall Dr.
Harleysville, PA 19438
215.256.6601
www.pittmannet.com

Pittman makes good, reliable gearhead motors. These are common at robotic combat competitions.

Micro Mo Electronics, Inc.
14881 Evergreen Avenue
Clearwater, FL 33762-3008
813.572.0131
www.micromo.com

High-quality aerospace gearmotors. These are above the budget of your average Robot wars competitor, but are highly recommended if you can handle the cost. You may find them via a surplus dealer.

Starter Motors

Sullivan Products
1 North Haven Street
Baltimore, MD 21224
410.732.3500

Sullivan makes very powerful motors intended for starting RC aircraft motors. These are used by many of the top middleweight and heavyweight robots, including La Machine, Vlad, The Alexander, and Turtle Roadkiller. Be warned, however, that these motors are **not** designed for continuous use under load, and require lots of cooling.

Other Motors

Astro Flight, Inc
13311 Beach Ave
Marina Del Ray, CA 90292
310.821.6242
www.astroflight.com

Astro Flight makes a line of very powerful (and expensive) electric aircraft drive motors, gearboxes, motor controls, and battery chargers. They also make very high quality wiring and connectors, highly recommended for your robot!

Cordless power drill motors were very popular in the lighter weight classes. I haven't used these myself and don't know of specific cheap sources for them, but check out your local Home Depot, hardware store or power tool repair shop for pricing on these.

Speed Controllers

Vantec
460 Casa Real Place
Nipomo, CA 93444
805.929.5055
www.vantec.com

Vantec speed controllers have become *the* standard at combat competitions. They make a line of dual-channel speed controllers, originally developed for bomb disposal robots and power wheelchairs. These speed controllers are very reliable but are not cheap: the low-end RDFR22 used in Spike cost $260, and that was one of their *cheapest* models. Many robots in the smallest weight class used Tekin and Novak brand RC car speed controllers. As with all controllers, do not over-extend them as I did when I used Tekin Rebels for Spike I in 1996.

Model Control Devices
P.O. Box 173
Bobcaygeon, Ontario,
CANADA
KOM 1AO
705.738.1335
www.modelcontrol.com

Model Control Devices makes several remote-controlled switching modules useable for Robot Wars, as well as a few good models of speed controllers.

Surplus Dealers

Servo Systems Co.
115 Main Road
P.O. Box 97
Montville, NJ 07045-0097
973.335.1007
800.922.1103
www.servosystems.com

Servo has a good selection of new and surplus industrial motors, and industrial motor control equipment. This is where I found the high powered Clifton Precision drive motors used in Spike II.

Surplus Center
1015 West "O" Street
P.O. Box 82209
Lincoln, NE 68501-2209
800.488.3407

Everything you need for a hydraulic powered robot: hydraulic pumps, motors, cylinders, valves, and assorted gas engines. This catalog inspired the creation of "Chew Toy." It also has a good selection of electric motors and miscellaneous mechanical parts.

Electronic Surplus, Inc.
5363 Broadway Ave.
Cleveland, Ohio 44127
216.441.5577
www.electronicsurplus.com

Miscellaneous electronic components (9000 different semiconductors), test equipment, batteries, motors, sensors, optics, and relays which may be of use for Robot Wars.

All Electronics Corp
14928 Oxnard Street
Van Nuys, CA 91411
800.826.5432
www.allcorp.com

Surplus electronics parts. The low prices make the hit-and-miss aspect worth your while. This is where I bought the motors and batteries used in Spike I.

American Science and Surplus
3605 Howard Street
Skokie, IL 60076
847.982.0874
Fax 800.934.0722
www.sciplus.com

Lots of random stuff. Catalog has a few gems in it and the prices are low. Worth a look.

Marlin P. Jones & Assoc., Inc
P.O. Box 12685
Lake Park, FL 33403-0685
800.652.6733
www.mpja.com

Assorted surplus electronics stuff. Call for catalog. RS&T

Author **Ronni Katz** built ChewToy after 3 years of Robot Wars™ experience with Spike, and two years of interviewing fellow robot warriors. Her day job is programming, and her past life was landing on aircraft carriers. Her action-packed novel, *Wing Commander*, is available at major bookstores (ISBN 0-9662083-0-7) under the pen name Ron Karen. We at RS&T are proud to have her on our pedagogical team.

Walking Robots, continued from page 30

Vision-Based Navigation

Each legged robot used in RoboCup '98 was equipped with a single perception sensor, a vision camera. The hardware-based vision processor provided robust eight-color discrimination. Robots need to act solely in response to the visual input perceived, and Carnegie Mellon decomposed this task along the following lines:

Reliable detection of all of the relevant colors. Orange (ball), light blue (goal and marker), yellow (goal and marker), pink (marker), light green (marker), dark blue (teammate/opponent), and dark red (opponent/teammate).

Active ball chasing. The robot actively interleaves searching for the ball and localization on the field to evaluate both an appropriate path to the ball and final positioning next to the ball.

Game-playing behaviors. Robots play attacking, and goal-keeping positions.

Learning of Color Thresholds

The Sony legged robot has specialized hardware for detecting eight colors. The hardware still requires pre-setting of appropriate thresholds in color space for the desired colors. It is well known that color adjustments are highly sensitive to a variety of factors, such as lighting and shading. The current version of the robot used for research can only react to this colored-vision perception.

In order for a robot to act in the world, it necessarily needs to address the signal-to-symbol problem, i.e., the robot needs to map its perception signals into its operating system.

In the robotic soccer task, using only color-based perception, the symbols of the task are all color-coded: the ball is orange, the goals are yellow and blue, the markers around the field are distinguished by two ordered colors, and opponents and teammates are dressed in different color uniforms.

Processing of the colored image to detect objects is extremely delicate, as slight modifications in the thresholds may correspond to dramatic changes in the set of objects detected.

Figures 2 and 3 illustrate this point. The figures show a tool to visualize the effect of changing the ultra-violet thresholds on the parts of the image that are going to be detected. Each of the figures shows, on the left, several images as seen by the robot. Those images are mapped into the ultra-violet color space as shown in the center section of the figures. In the center space, thresholds can be set manually and are shown as the rectangles in the image, and the resulting areas detected are shown on the right side. The main point to gather from the figures is the change of the green thresholds between figures 2 and 3. That leads into a different detection of green areas in the images. The goal is for the thresholds to be accurate enough so that what is detected as being of some color corresponds to a unique object. For example, there is a light green landmark and the field is of a darker green. Since the robot doesn't need to use the field for any reasoning, it is necessary that the ultra-violet color threshold for green detect only the light green color of the landmark. If this threshold is set correctly (as in Figure 2),

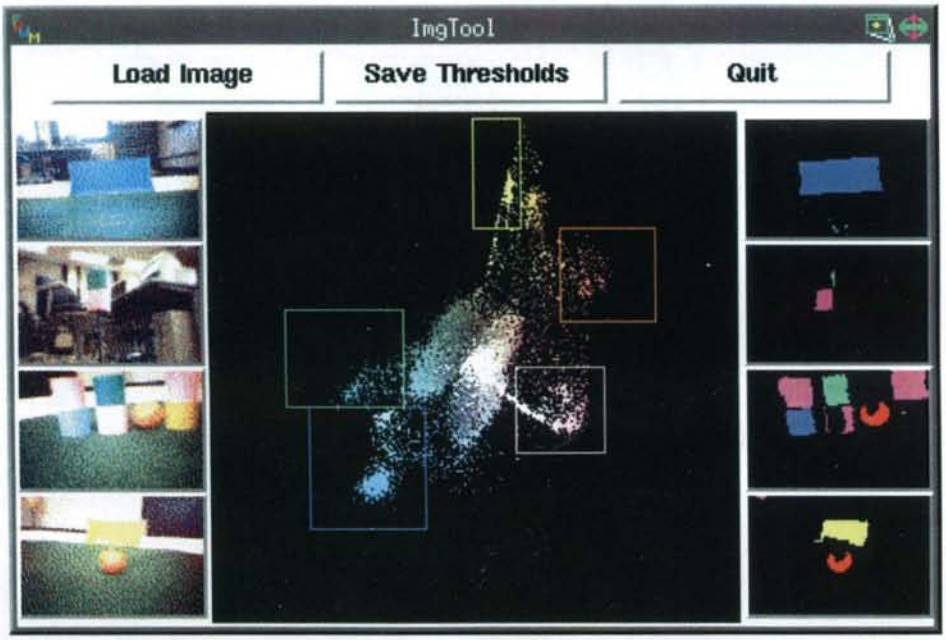


Figure 2

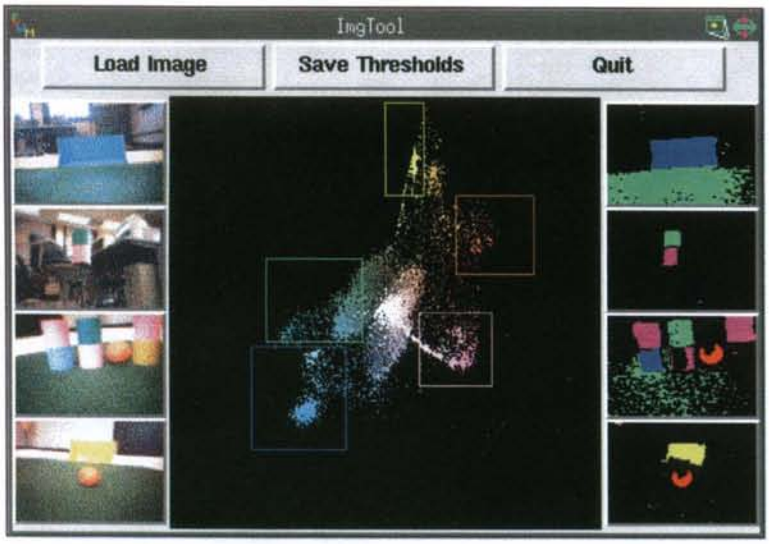


Figure 3

then all the objects detected as green are indeed part of a colored landmark.

Setting up manually and accurately the color thresholds is a very difficult task, so Carnegie Mellon developed an automatic methodology for acquiring the necessary thresholds.

They developed a classification algorithm to automatically learn the thresholds that maximize the accuracy of the desired color detection. The algorithm relies on supervised classification using a set of training and testing images. By moving the robot to different positions on the field, a series of images are accumulated. For each image, regions of the different colors are manually classified. This manual labeling is easily done through an interface that overlays the original image, and the manual classification. Areas of the image can have their correct classification specified using tools similar to PC-type paint programs. Figure 4 shows an image where a region has been manually selected and classified as orange.

Once the data has been classified, the color thresholds are learned separately for each color, using a conjugate gradient descent-based algorithm. Each threshold is softened by replacing it by a sigmoid function:

Formula 1: Sigmoid Function

$$C = \frac{1}{1+e^{t(a-x)}}$$

where **C** is the classification for this sigmoid, **a** is the value of this threshold and **t** is a variable equivalent to the current temperature in a simulated annealing algorithm.

The classifications of the different thresholds are multiplied and a conjugate gradient descent is performed on the sum-squared error. Initially the temperature is quit high. It is reduced gradually over time as the sigmoid are learned.

In CMU experiments, about twenty images were use for training. The learning algorithm converges in les than one hour, and achieves a high classificatio accuracy.

The learning method for achieving automated colo calibration is summarized:

Training:

- Gather images from different field positions
- Manually classify each region in each image

Objective: maximize accuracy of color detection

Algorithm:

- Adjust smooth sigmoid color thresholds
- Minimize the sum-squared error of the combined classifications of all thresholds
- Use conjugate gradient-descent

Performance: 20-50 training images, < 1 hour convergence

Bayesian Probabilistic Localizatio

The CMTrio team used Markovian localization to determin position on the field.

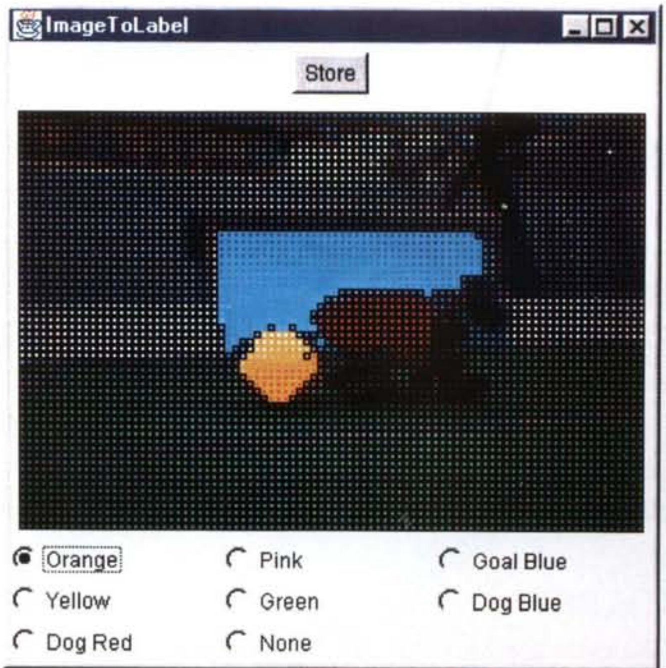


Figure 4

Relying on dead-reckoning (track, or distance and direction made good) for localization was not possible, since it is unreliable and lacks requisite accuracy, so the CMU team developed a Bayesian localization procedure around the fixed colored landmarks. Since the robot cannot keep enough markers in view at all times to calculate its location directly, the algorithm used a probabilistic method of localization, triangulation based on two landmarks.

To accomplish this, the field is discretized into grid locations, i.e., a continuous vector space is divided up into discrete sections. The continuous robot head angles are also discretized. We create a state space with these discretized grid cells and robot headings. Observations of the landmarks are combined with the state space for the position calculation. There are two passes to our localization algorithm; (1) incorporates observations into our probability distribution, and (2) takes into account the movement actions selected. Incorporation of observations is based upon Bayes' Rule:

Formula 2: Bayes' Rule

$$P(S_i \mid O) = \frac{P(S_i)P(O \mid S_i)}{\Sigma_j P(S_j)P(O \mid S_j)}$$

where $P(S_i)$ is the apriori probability that the robot is in state S_i $P(S_i \mid O)$ is the posterior probability that the robot is in state S_i given that it has just seen observation O and $P(O \mid S_i)$ is the probability of observing O in state S_i.

To represent the probability distribution $P(S_i)$, a table of values is used. The table is a three dimensional mapping: $X \times Y \times \theta \mid S_i$. A table of values was chosen because some of the distributions that need to be represented do not have an ideal, parametric form. For instance, given a uniform prior distribution, the observation of the angle between two markers gives a high probability circle through the state space that is not representable by a Gaussian distribution.

Incorporation of movement is based upon a transition probability matrix.

Specifications of Prototype Robot

Quadruped Configuration	4-Legged Autonomous Robot
• **CPU**	MIPS 64 Bit RISC Processor
• **Main Internal Memory**	8MB DRAM
• **Operating System**	Aperios
• **Supplemental Memory**	PC Card (Type II, 2 slots)
• **Video Input**	CCD Color Video Camera (1/5 inch, 180,000 pixels)
• **Audio Input**	Stereo Microphone
• **Audio Output**	Speaker (Mono)
• **Movable Joints**	16 Total degrees-of-freedom •4 legs with 3 degrees-of-freedom •1 Head with 3 degrees-of-freedom •1 Tail with 1 degree-of-freedom
• **Walking Speed**	About 5 meters per minute
• **Batteries**	One 7.2V Rechargeable Lithium-ion One 4.8V Rechargeable Nickel-Cadmium
• **Maximum Dimensions (mm)**	132W X 250H X 235L (not including tail)
• **Weight**	1.25 kg (including batteries)
Installed Application Module	
• **Movement/ Behavior**	Walking,sitting, standing, sleeping, various motions
• **Image Processor**	Color region recognition, motion detection, etc.
2-Wheeled Rolling Module	
• **Movable Parts**	2 degrees-of-freedom
• **Maximum Dimensions (mm)**	160W X 128H X 72W

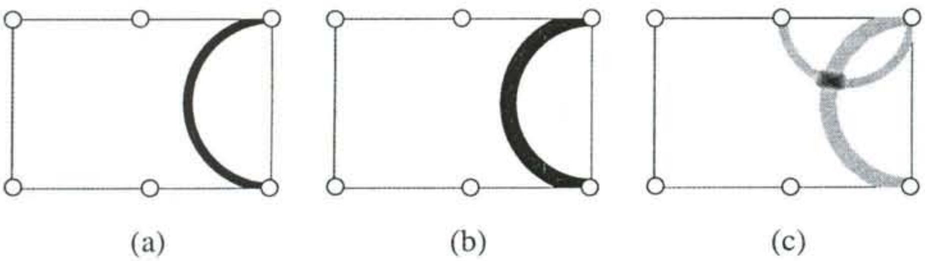


Figure 5: The positioning probability: (a) after the first observation; (b) after a 90 degree turn; (c) after the second observation.

Given a previous movement **M**, for each state, the algorithm computes the probability that the robot is in that state:

Formula 3: Transition Probability

$$P(S_i \mid M) = \Sigma_j P(S_j)P(S_j \rightarrow S_i \mid M)$$

$P(S_j)$ is the a priori probability of state S_j and $P(S_j \rightarrow S_i \mid M$ is the probability of moving from state S_j to state S_i given the movement **M**. It is assumed that the transition probabilities, $P(S_j \rightarrow S_i \mid M)$, take into account any noise in **M**.

For example, imagine that the robot sees an angle of 90 degrees between two markers, turns to the left and then sees an angle of 90 degrees between two more markers. Initially it does not know where it is—our prior distribution is flat. After its first observation, the projection of the state probability matrix onto the X,Y plane would be as shown in Figure 5a. During the turn, the projection spreads over the X,Y plane representing the increased uncertainty introduced by the dead reckoning as the robot turns, see Figure 5b. The second observation finally localizes the robot, see Figure 5c.

The localization algorithm is invoked actively, i.e., the robot searches for two landmarks when the maximum state probability is below a pre-defined threshold. In CMU experiments, the robots have localized themselves with a high degree of accuracy.

Role-Based Behaviors

Following up on experience with the small-size RoboCup wheeled robots, CMU developed different behaviors based on positioning on the field. The quadruped soccer-playing robots are now able to play two different roles, attacking and goal keeping.

The procedure used by an attacking robot consists of the following steps: (1) find the ball; (2) localize attacking goal; (3) position behind the ball, aligned with the goal; (4) shoot or pass.

The procedure used by the goal-keeping robot consists of the following steps: (1) find the ball; (2) remain close to the goal; (3) move sideways aligned with ball; (4) clear the ball when it gets close to it.

Conclusion

CMU and Sony have worked closely together to demonstrate successfully a new system architecture that allows legged soccer robots to operate effectively as teammates in a complex, changing environment.

Those responsible for introducing the OPEN-R architecture into robotics point out that, for now, its purpose is to provide a method for accelerating the development of robotics and artificial intelligence in entertainment robots. Asked about the future of the architecture, Masahiro Fujita said, "Once OPEN-R is accepted by many users and developers, progress in the use of artificial intelligence in robotics will occur at a rapid pace. We are keeping in mind the upgradability of OPEN-R so that it will be able to evolve easily as hardware and software improvements take place."

Biographies

Professor Manuela M. Veloso is Associate Professor of Computer Science at Carnegie Mellon University (CMU). She graduated from the Instituto Superior Tecnico in Lisbon, Portugal, where she earned a BS degree in Electrical Engineering in 1980, and an MS degree in Electrical and Computer Engineering in 1984. She attended Boston University, where she received an MA in Computer Science in 1986, and received her Ph.D. in computer science from CMU in 1992. Professor Veloso investigates methods for individual behavioral and strategy learning for teams of multiple robots acting in an adversarial environment.

Masahiro Fujita is Senior Research Scientist and System Architect at the D21 laboratory at Sony headquarters in Japan. He earned a BA degree in Electronics and Communications from Waseda University, Tokyo, in 1981, and an MS degree in Electrical Engineering from the University of California, Irvine in 1989. At Sony, he is in charge of the development of autonomous legged robots for entertainment applications, and establishment of OPEN-R, a standard architecture for entertainment robots.

William Uther is a doctoral student in Computer Science at Carnegie Mellon University. He earned his B.Sc. degree in Computer Science, with honors, from the University of Sydney in 1994. Mr. Uther, who implemented the CMTrio RoboCup '98 team, is currently investigating the use of reinforcement learning for agent control and how to automatically decompose problem spaces based on experience.

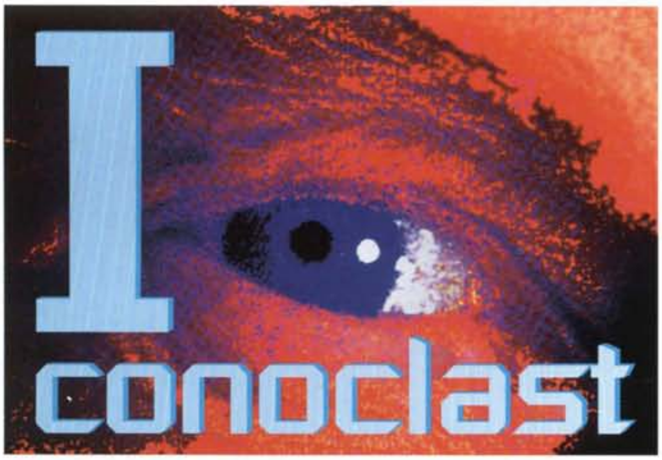
RS&T

Congratulations to the **Carnegie Mellon students and faculty** who were members of the winning teams at RoboCup'98:

CMU Simulation Team
Peter Stone, Manuela Veloso and Patrick Riley

CMU Small-Robot Team
Manuela Veloso, Michael Bowling, Sorin Achim, Kwun Han and Peter Stone

CMTrio Legged Robot Team
Manuela Veloso, William Uther and Kwun Han



Your Robot is Ugly

Whenever I'm unexpectedly confronted by a chasm of ignorance, misunderstanding, and aesthetic values it's hard to know how to respond to the cretin.

The story is told that, in 1787, Grigori Potemkin built impressive fake village fronts along a route that Catherine the Great was to travel, in order to hide their true appearance. This apocryphal story came to mind as I was talking to a newspaper editor who had returned from covering a robot contest. I was really ticked when he said, "I don't really like boring robot bodies, do you? And why do people use plywood and castors, anyway?" Mega Sigh.

Whenever I'm unexpectedly confronted by a chasm of ignorance, misunderstanding, and aesthetic values it's hard to know how to respond. One could just ignore the cretin and move to another topic ("I suppose they try. So what was the weather like in Calgary?"), be politically correct and mumble something inoffensive ("Yes, a thing of beauty is a joy forever"), turn defensive ("You know, it's pretty hard to make these things"), turn offensive ("Well, did you ever *build* one, pinhead!?"), or try to bridge the gap and educate the person.

But where does one start? With a lesson about the practicality of building materials? By pointing out that what's exciting is in the capabilities, not the appearance? Should one try to explain that these robots are development platforms? Make a comparison between the old style Detroit cars marketed on styling and the Japanese cars that went twice as far on a tank of gas and ran for 200,000 miles? I find it exasperating that people will often choose style over performance, format over content, form over function.

People use plywood because it's cheap, readily available, and easy to work. One can use other materials to some degree, but bending and shaping metal and plastic takes more time, equipment, hardware, and expense than working with wood. Look around Home Depot. How many plastic and metal working tools do you see that aren't primarily woodworking tools? There are a lot of practical reasons to use wood for the basic platform, especially for small robots and small budgets.

Furthermore, most robots are works in progress. They're not commercial units nor are they meant for sales in Toys 'R Us. I have to guess that most amateurs are like me in that their robot design starts with an idea, a goal and a plan to achieve it, but not with a CAD drawing. One improvises as one goes along and wood is easier to work with. "Hey, let's try attaching one of those gizmos over here. No problem, we'll just screw it in." The design and improvement of a robot platform depends in part on the feedback that comes from the robot's performance, its interaction with its environment, and especially from its failure modes. After some amount of trial and error, adjustments, work-arounds, patches, re-wiring ... well, it's a mess and time for a total rebuild.

> Did you ever *build* one, pinhead!?

Actually, once I get the performance I like, *then* I'll think about making it pretty. Until then, my bot is mostly for my personal entertainment and for sharing with other gearheads, who aren't primarily concerned with the robot's looks. Sure, I can gussey it up, and my Aunt Susy would be impressed even if it were just radio controlled. But long before the platform is perfected, it has achieved 90% of its goals and it's time to move on to something else. But who wants to rebuild *then?*

A boring robot body is not the same as a boring robot. I've seen several nice looking robots that simply didn't work well. The best place to witness this is at a contest where there are plenty of entries with the same, well-defined goal. One of the winners of Robot Wars(tm) had an inverted metal wash tub for its outer shell. It may have been ugly, but it wasn't boring. The same is true in many other contests. Nobody seems to care if the winner is made of plywood and sealing wax.

I suppose that, in order to advance robotics, we should also try to appeal to newspaper editors and their readers, as long as we do it in an honest way. So maybe the next time I enter a contest I'll improve the robot's appearance with some paint and flashing LED's. Right. Maybe I'll name it Potemkin.

November 14, 1998, *Western Canadian Robot Games*

Calgary, Canada—http://www.robotgames.com

The WCRGs, to be held at the Calgary Science Centre (Planetarium), are devoted to promoting robotic science and technology. The games are open to the public, and robot designers of all ages are invited to demonstrate their robots and compete for prizes. The web site provides a description of events, rules and regulations, registration information, and lists sponsors. The registration form is online, and you can contact: info@robotgames.com. *RS&T's first-hand report of last year's WCRG is at www.RobotMag.com.*

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

Manchester, N.H—http://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. *High school teams should find corporate sponsors and be registered by early December. Call 800.871.8326 for assistance.*

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 25-27, 1999, *FIRST Open Regionals*

(Two locations)—http://www.usfirst.org

William Rainey Harper College, Palatine, IL
NASA Ames , Moffett Field, Mountain View, CA
Say "hi" and be nice to the RS&T reporters.

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

Los Angeles, California—http://www.sme.org

Annual metalworking and manufacturing exposition, held at the Los Angeles Convention Center, will include a new metal forming and fabricating pavilion and job shop pavilion. Sponsored by the Society of Manufacturing Engineers, American Machine Tool Distributors' Association and the Association for Manufacturing Technology.

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

Hartford, Connecticut—http://www.trincoll.edu/robot

The challenge for entrants is to produce a robot that can move through a model of a single floor of a house, detect fire and put it out. There is a junior division for high school students and younger, and a senior division. Other events include seminars and a robotics exhibition. For additional information, contact: jmendel141@aol.com. *See RS&T's Premier Collector's Edition for robot construction ideas. Also see www.RobotMag.com.*

BASIC Stamp® Computers

Application ideas and Parallax Fall events

BASIC Stamps are small computers programmed in Parallax BASIC (PBASIC), a simple programming language with powerful I/O instructions to control external circuitry. There's no shortage of application ideas using BASIC Stamps. Take a look at our manual (23 AppNotes), Scott Edwards Programming and Customizing the BASIC Stamp book (11 AppNotes), and Nuts and Volts Magazine (over 30 regular columns). If you've got an idea and want to know if it will work with a BASIC Stamp, please call and ask for one of our tech support staff.

BASIC Stamp I Starter Kit #27205 - $99
BASIC Stamp I module #BS1-IC - $34

BASIC Stamp Rev.D Starter Kit #27202 - $79
BASIC Stamp Rev.D module #27100 - $34
(Rev.D not shown)

JP Aerospace, "America's other space program" is a competitor in the private race to space. The Davis, California, group has flown to 100,000 feet at speeds over Mach 2 miles. With their 8-foot rocket, they hope to reach space by the end of 1998. Camera control, altimeter data logging, and parachute deployment are controlled by a BS1-IC module. Program details are shown at **http://www.jpaerospace.com**

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COMDEX®

BOOTH S8152 Sands Lower Level
November 16 through 20, 1998
Las Vegas, Nevada
Free tickets available at our website **http://www.parallaxinc.com**

BASIC Stamp II Starter Kit #27203 - $149
BASIC Stamp II module #BS2-IC - $49

Programming & Customizing the BASIC Stamp Computer book by Scott Edwards #27951 - $34

EMBEDDED SYSTEMS CONFERENCE

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Ideal place to learn about our range of development tools for the SX microcontroller.
Booth 5061, San Jose Convention Center
San Jose, California
November 1 to November 5, 1998
Register at http://www.embedded.com

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PARALLAX

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