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# SERVO

FOR THE ROBOT INNOVATOR

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MAGAZINE

January 2014

## SPRITE
## RASPBERRY PI POWERED ROBOT TESTBED FOR EXPERIMENTERS



- RoboBusiness 2013
  Event recap
- Windows 8 Tablets
  The ultimate robot controller?
- Robot Wars: Roomba vs. Neato
  See how they stack up

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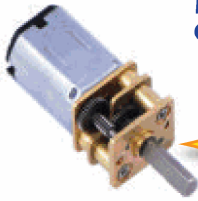
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- 40 g
- Specs at 6 V:
  - 71 RPM
  - 93 oz-in

### Micro Metal Gearmotors



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Other sizes available

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ITEM #1337

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Programmable MCU module featuring a 2.4 GHz radio and USB: write your own software or load precompiled, open-source apps.

### 3pi Robot

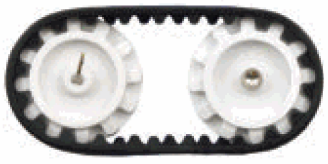


ITEM #975

$99.95

The 3pi is a great first robot for ambitious beginners and a perfect second robot for those looking to move up from non-programmable or slower beginner robots.

### 22-Tooth Silicone Track Set



ITEM #1415

$12.95

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STARTING AT

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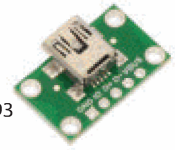
- Center positive, 5.5 mm × 2.1 mm barrel connector
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ITEM #2593

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ITEM #713

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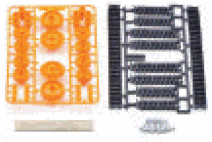
- DRV8833 driver
- 2.7 V to 10.8 V operating range
- 1.2 A continuous (2 A peak) per channel

### Tamiya 70097 Twin-Motor Gearbox Kit

ITEM #61

$8.95





### Tamiya 70100 Track and Wheel Set

ITEM #106

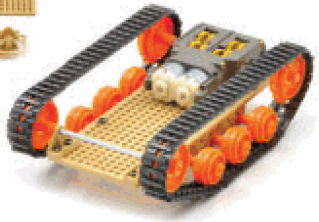
$7.95

### Tamiya 70098 Universal Plate Set

ITEM #79

$6.25





Our large selection of Tamiya gearboxes and construction sets is great for building inexpensive mechanisms and robot chassis!

### Crimping Tool



ITEM #1928

$34.95

### 26 AWG Red Stranded Wire, 70 ft



ITEM #2622

$4.50

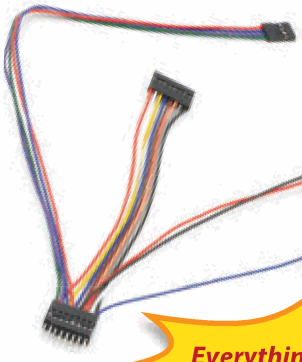
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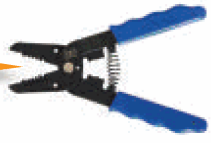


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### 16-26 AWG Wire Stripper



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SERVO MAGAZINE

01.2014
VOL. 12 NO. 1

# Columns

**08 Robytes**
*by Jeff Eckert*
***Stimulating Robot Tidbits***
- Flying Bugbot Out of the Woods
- In Your Face — and Beyond!
- Forget Mint: Here Comes Mab
- Budgee in Your Budget?
- Bookbots in the Sky

**12 GeerHead**
*by David Geer*
***One Man and an Idea***
See what DJ Sures is doing at EZ-Robot Revolution for the future of robotics.

**16 Ask Mr. Roboto**
*by Dennis Clark*
***Your Problems Solved Here***
Questions on analog vs. digital servos, battery charger selection, and temperature sensors for 3D printers are discussed.

**74 Then and Now**
*by Tom Carroll*
***Robot Wars: Roomba vs. Neato***
See how these robot vacuums stack up against each other.




## The Combat Zone

**30 BUILD REPORT:**
Isotelus Rex — Part 1

**34 PARTS IS PARTS:**
*Product Review:*
FingerTech Robotics tinyMixer

**35 EVENT REPORT:**
The Adventures of Scary and Angry Bot

**39 EVENT REPORT:**
Franklin 2013 — Fall Fun at Philly

**44 THEN AND NOW:**
A Decade Later With Alexander Rose

# Departments

**06 Mind/Iron**
*A Ton of Features vs. a Ton of Bricks ...*

**20 Events Calendar**

**22 New Products**

**25 Showcase**

**64 SERVO Webstore**

**80 Robo-Links**

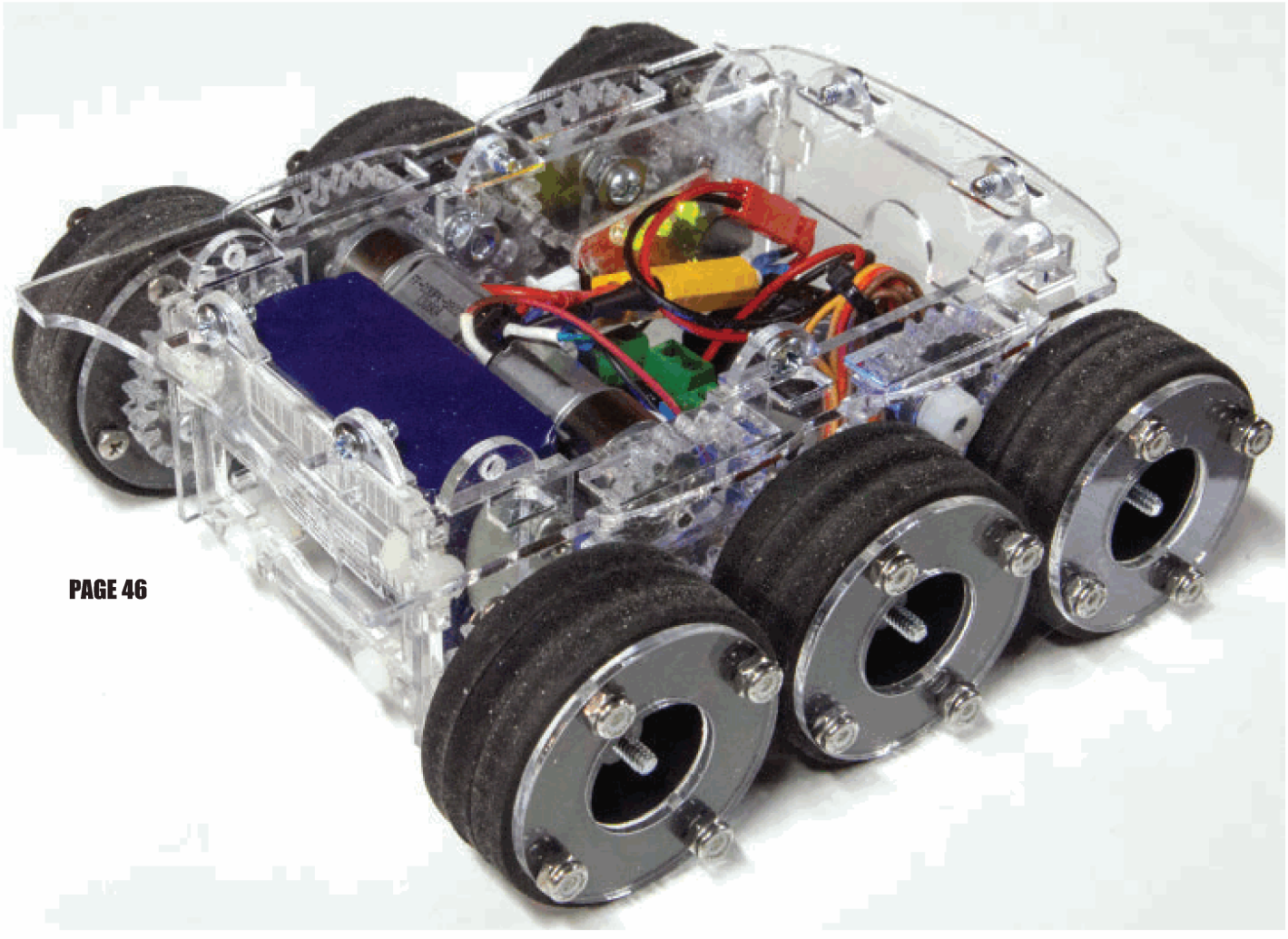
**80 Advertiser's Index**

**26 Bots in Brief**
- Tail Tale
- Take Out the Trashbox
- Dream Ringer
- Robot Rock Climber
- Bot Toss



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# In This Issue ...



PAGE 46


## 46 Build the Plastic Bot of Destruction — Part 3

*by Michael Simpson*

PBOD gets some major design changes.

## 53 RoboBusiness 2013: A View from the Expo

*by Camp Peavy*

A quick recap of the recent event.

## 56 SPRITE: Simple Pi Robot Interactive Testbed for Experiments

*by William Henning*

Build this multi-purpose robot base geared toward the hobbyist (or student) to experiment with to your heart's content.

## 68 Windows 8 Tablets: The Ultimate Robot Controller — Part 2

*by John Blankenship and Samuel Mishal*

Learn how to integrate the tablet's sensors by first using it as a steering wheel, then taking advantage of the tablet's compass to maintain a robot's heading.




# Mind / Iron

*by Bryan Bergeron, Editor*

## A Ton of Feathers Versus a Ton of Bricks ...

If you've devoted much time experimenting with robot arms, then you've undoubtedly spent considerable time and money repairing the servos and motors. I've probably fused a half dozen HiTec servos on one robot arm alone. I never really appreciated the abuse I subjected the servos to until I added club swinging — essentially swinging metal and wooden bats in circular paths around the body — to my exercise routine of kettle bells and free weights. It's one thing to look at torque specs on a spreadsheet and quite another to experience dynamic variances in torque involving your own shoulder, elbow, and wrist joints.

Take a look at the photo — two clubs from my collection and a neoprene bag of lead shot. All three have the same mass — about 15 lb of lead, iron, or beech wood. As you'd expect, at rest with my arm extended, the load on my rotator cuff muscles is the same. However, when swung overhead, the clubs are much more of a challenge than the bag of lead shot. Moreover, swinging the beech wood club is most difficult of all. This makes sense, given the center of gravity of the wooden club is farther away from the club handle than is the center of gravity of the metal club.

I don't know the rating of my shoulder joints, but a typical servo (such as the HiTec HS-311) is rated at 51 oz-in and 0.15 sec/60 degrees with a supply voltage of 6V. In other words, given a 6V supply and a 1" servo arm, you would expect the servo to supply 51 oz of force at right angles to the tip of the arm, and move the 51 oz weight 60 degrees in 0.15 seconds. Use a 10" servo arm and — neglecting the weight of the arm — you'd expect the servo to generate a 5.1 oz force at right angles to the tip of the arm.

The point is the real world of robotics isn't about carefully slowly picking up a 6 oz plastic ball and placing it in a slot. Today, it's about wielding tools and torches at high speeds, and tomorrow about lifting patients from beds and rescuing victims from collapsed buildings. Even if you're just designing a simple arm for your next hoops competition, you've got to consider the real world forces involved.



Now, it's one thing to examine the stresses on a robotic arm or other robotic device using simulations and mathematical models. It's another to develop an intuition for what works and what doesn't. For example, pick up a baseball bat and carefully swing it in a vertical arc. Pay attention to the stresses on your shoulder joint and muscles. At the apex of the swing — where gravity and centrifugal forces are equal but opposite — you might feel very little. You'll probably feel a significant tug just after the club travels past your feet. Now try the same swing with your hands alone and again while holding, say, a plastic bottle filled with water.

Pay attention to your elbow,



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wrist, and shoulder joints.

Once you develop a feel for what rotation can do to a mass attached to an extension of your arm — or to a robot arm — you'll better appreciate what's allowable before damage likely occurs. For example, I've come to appreciate that those small but sudden stops and starts are deadly to servos, even when the robot arm is unloaded. I'm also more careful about parking my robot arms in safe positions so they don't lurch into position when power is applied.

If you're the quantitative type, then you can use the iPhone's internal accelerometer and Bluetooth peripherals to measure the forces generated during a swing. For example, I've measured over 3 gs with a handheld iPhone running techBASIC during a normal swing of one revolution/second. Using a TI SensorTag mounted at the 15 lb beech wood club's center of gravity, I've measured over 5 gs – that's 75 lb. Quite a tug.

For more information on techBASIC ($20) and the TI SensorTag ($99), check out **www.byteworks.com**. If you're interested in the biomechanics of Indian club swinging, check out the videos and clubs on Dr. Mike Simpson's excellent website at **www.indianclubswinging.co.uk**. **SV**

I just noticed a glaring error in my December 2013 Then & Now column! I said ***Ackermann*** steering when I meant to say ***differential*** steering in the paragraph shown below (on page 79). My sincere apologies.

Tom Carroll

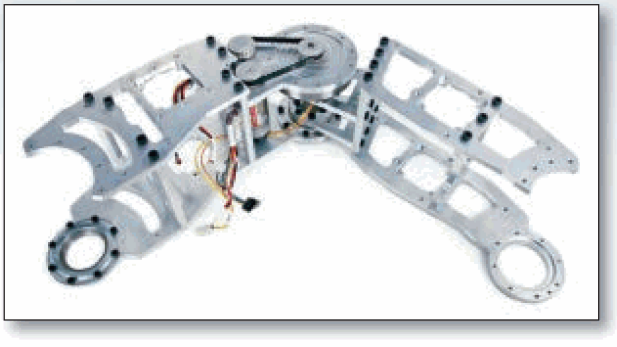
*Several robot suppliers carry this base and some add their own drivers. The $350 Parallax version includes two of the Parallax HB-25 fan-cooled motor controllers and also a Propeller project board. The six wheels are independently spring-loaded to traverse rough terrain but do have **Ackermann** steering.*


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Shown below is an articulated humanoid robot leg, built by researchers at the Drexel Autonomous System Lab (DASL) with a Tormach PCNC 1100 milling machine. DASL researcher Roy Gross estimates that somewhere between 300 and 400 components for "HUBO+" has been machined on their PCNC 1100. To learn more about this project, visit www.tormach.com/servo.





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# Robytes

by Jeff and Jenn Eckert

## Flying Bugbot Out of the Woods

Many flying robots employ sophisticated collision avoidance systems but sometimes dumber is better, as evidenced by a dual-propeller whirlybird recently developed at the École Polytechnique Fédérale de Lausanne (EPFL, **www.epfl.ch**). The "Gimball" — like a fly that keeps bumping up against a window until it finds an open area — just collides with obstacles, bounces off undamaged, and keeps going. The key is a 34 cm (13.4 in) spherical elastic cage that continuously rotates and absorbs shocks while a gyroscopic stabilization system keeps the robot inside vertically oriented. The lack of the usual complex network of sensors also allows for a major reduction in weight, with the Gimball tipping the scales at only 370 g (13 oz).



*The Gimball flying bot crashes but doesn't care.*

In a test, the unit managed to navigate through several kilometers of Swiss pine forest using only a compass and altimeter, even though it collided with several tree trunks along the way. It does sport an onboard camera that can be used to relay information to personnel in earthquakes and other emergency situations but it is not used for navigation, so Gimball can operate just fine in places like collapsed buildings and other disaster areas — even if they are full of smoke. It's pretty impressive, but PhD student Adrien Briod had to admit, "We're not ready to compete with our model [flying bugs]. Insects are still superior."

## In Your Face — and Beyond

This month's nominee for the creepiest robotic breakthrough is a prototype intubation device that crawls into an anesthetized or critically sick patient's lungs. According to its developers at the Hebrew University of Jerusalem (**http://new.huji.ac.il**), doctors who manually insert plastic tubes into patients have to look down into the trachea and "choose between two very similar holes: one leading to the lungs, the other to the stomach. Failure to identify the correct hole can lead to patient death." On top of that, the process is even more difficult on the battlefield or in other situations where the patient may have blood or other liquids in the way.

Biodesign program students at the university have come up with the "GuideIN Tube" which uses an infrared source to identify the lung hole and navigate into it. Reportedly, it has been tested successfully on cadavers, and clinical trials on live subjects will begin this year.

"I strongly believe that GuideIn Tube represents the future of intubation," observed Dr. Elchanan Fried, director of the general intensive care unit in Hadassah Medical Center. The device targets a $3 billion market which is expected to increase by five percent annually.



*Video frame showing the GuideIN Tube being inserted into a simulated patient's head.*

Go to **www.servomagazine.com/index.php/magazine/article/january2014_Robytes** to comment on these topics.

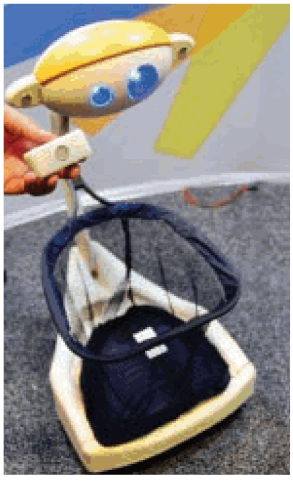
## Forget Mint: Here Comes Mab



*Mab in operation: A swarm of flying microbots cleans surfaces all over the house.*

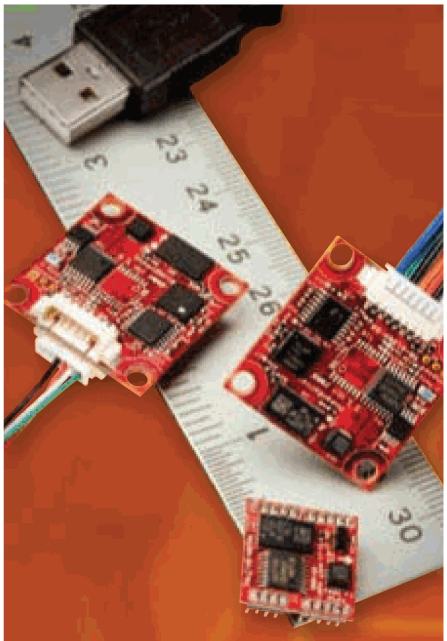
Every year, the Electrolux Design Lab (**electroluxdesignlab.com/en/**) sponsors a design competition, which in 2013 drew submissions from more than 1,700 students worldwide. This year's first place winner is "Mab" — the brainchild of Adrian Perez Zapata, a university student from Colombia. The Mab concept envisions an automated cleaning system consisting of a central core and 908 flying mini bots that swarm around your house like bees. The bots detect dirt, swoop down on it, and wipe it up with a single drop of cleaning fluid. Mab operation involves five steps: (1) The system acquires energy from a "WiTricity" network, through a wireless charging system connected to the power supply, or by capturing solar energy through the microbot's wings. (2) The operator loads the special cleaning substance which is a mixture of water and a pleasant-smelling disinfectant. (3) The Mab core sends the bots out to scan the home and decides whether a "fast, normal, or exhaustive" cleaning job will take care of your particular level of griminess. (4) It schedules a weekly cleaning cycle and computes its required resources. (5) Finally, it links itself to any detected networks and devices (automation nets, computers, cell phones, etc.) so it can monitor their performance and receive commands from them. After that, it just works anonymously while you, Elroy, and Astro the Dog zip around Orbit City in your aerocar. Something tells me that Rosie isn't going to be happy about this.

## Budgee in Your Budget?



*Budgee, a robotic mini mule from Five Element Robotics.*

Much simpler and certainly much less ambitious is Budgee — a personal assistant robot that really doesn't do much at all. You just load his basket with up to 50 lb (23 kg), stick the Follow-me controller in your pocket, and he follows you around. According to his creator — Five Elements Robotics (**www.5elementsrobotics.com**) — "Budgee cares about you and wants to be your friend." If you give the controller to someone else, however, that friendship is likely to be seriously strained. At $1,400 a pop, Budgee may not seem like a wise investment for most individuals. Plus, he looks a little too much like the annoying kid from Family Guy with an eye infection. But it might make sense for grocery and big box stores to buy a fleet of them for people who are too unsteady for shopping carts but not quite ready for the scooters. In that case, it could be fun to put the controller from a second Budgee in the basket of the first one, the controller for Budgee no. 3 in no. 2's basket, and so on until you have a choo-choo train of them following you around. Until the manager throws you out, that is.

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## Bookbots in the Sky




*A Zookal book delivery bot: cheap to operate and greener than trucks.*

Commercial use of drones hasn't caught on in the USA, primarily because the FAA is still trying to figure out how to generate regulations to address the slew of privacy and safety concerns. However, the Aussies have been at it for quite a while. In fact, in 2002, they became the first country to allow and regulate the commercial use of unmanned aircraft. More than 50 licensed operators are already in business, mostly offering aerial photography and survey services. More recently, a company called Zookal (**www.zookal.com**) applied to the country's Civil Aviation Safety Authority for authorization to operate a textbook rental business that uses chopper drones for delivery. Reportedly, Zookal has raised $2.1 million from Silicon Valley venture capitalists to get started, so someone must believe in the concept.

The company will initially field a fleet of six battery-powered UAVs that can handle a payload of 2 kg (4.4 lb) and carry it up to 3 km (1.9 mi). This presents some obvious limitations, as the three-volume hardcover edition of *War and Peace* would max it out, and most customers are likely to live more than two miles away. According to company founder and CEO Ahmed Haider, "We expect the use of drones will cut our delivery costs from $8.60 to $0.80 per delivery, and because they are battery powered, the environmental impact is minimal."

If a bookstore is located on a college campus where significant numbers of students are too lazy or buzzed to walk that far, it just might work. Unless, of course, the students have heard of e-books. **SV**


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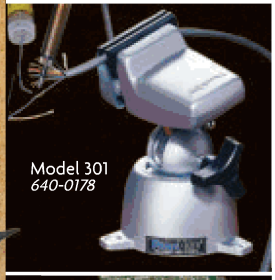
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# One Man and an Idea

## DJ Sures Helps Ensure the Future of Robotics Innovation

**EZ-Robot Revolution is a new platform that enables creative types and innovators to design and build robots with little or no knowledge of robot building or programming. This enables people to bypass the roadblocks of what they don't know how to do so they can see their idea come to fruition. Plus, it's always easier to start with the published work of other roboticists, which comes in the form of new parts and programming.**

Roboticist and CEO of EZ-Robot, DJ Sures designs, creates, modifies, and updates his platform largely from a lab in his home. This highly adaptable modular base has come a long way while sticking to its roots.



**Roli on rough terrain.** Here, Roli travels across rough, rocky, and jagged terrain — perhaps on a recon mission.

## EZ-Robot Revolution

EZ-Robot Revolution robots use a specially designed souped-up controller. The EZ-B v4 Wi-Fi robot controller brain runs a 32-bit processor at 120 MHz and uses a communication module that is a 32-bit processor running at 80 MHz. The camera uses a 32-bit processor, as well. "The platform also has fuse protection, so that if you over-drive the servos, you can reset the fuses simply by unplugging the power and plugging it in again," says Sures.

The EZ-Robot Revolution modular robot platform is versatile and customizable, while remaining extremely comptetively priced. It is small and precise, and comes with (smaller) parts such as adapters, extensions, and cubes. Roboticists can also design their own parts and print them on 3D printers. "We have two years of community crowd-sourced features built into every EZ-Robot Revolution product," explains Sures.

EZ-Robot uses an open hardware model that

enables users to design, create, submit, and print new 3D parts that they and other community members can use to greatly increase the augmentation capabilities of the Revolution platform.

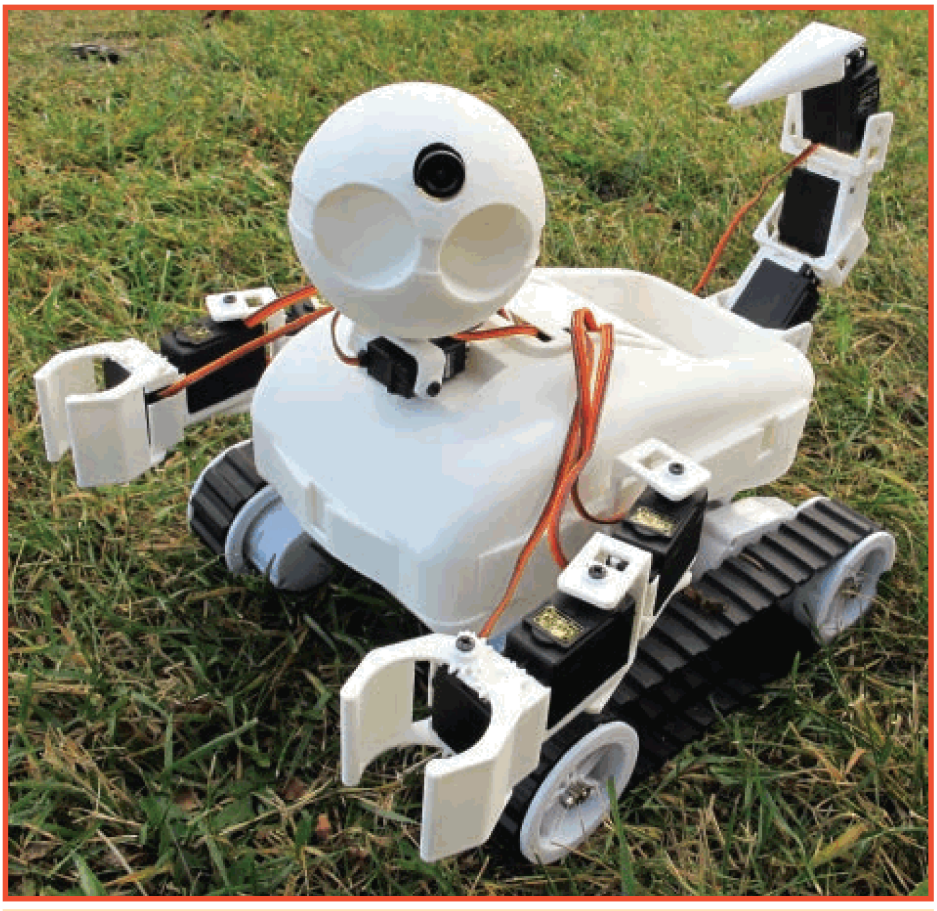
"That capability is built into EZ-Builder. We created a standard called EZ-Bit. We published the robot platform's dimensions free online and allow people to create their own parts on the EZ-Bits standard," comments Sures. When someone creates an EZ-Bit part, they simply submit that to the EZ-Robot server using the EZ-Robot EZ-Builder software. Then, EZ-Robot verifies the part and adds it to the existing library of 3D items available to anyone in the community. This is one way EZ-Robot Revolution gives everyone the power to innovate.

To program the robots, builders can use the auto positioning function to grab servos and move them into the different positions they want them to go in. The robot then records that information. With auto position, auto gating, and high precision servos, the robot can do this without ending up in strange, unnatural positions that might otherwise result from this programming approach.

The EZ-Robot software supports vision tracking cameras that connect via USB ports. EZ-Robot also has its own camera for the microcontroller board. This circuit board streams information across a Wi-Fi connection, according to Sures.

Software updates and capabilities based on demand from the EZ-Robot Revolution builder community are constantly added. For example, a student using the Revolution platform posted to the EZ-Robot forum that he would like to have his robot stop when it sees red and go when it sees green.

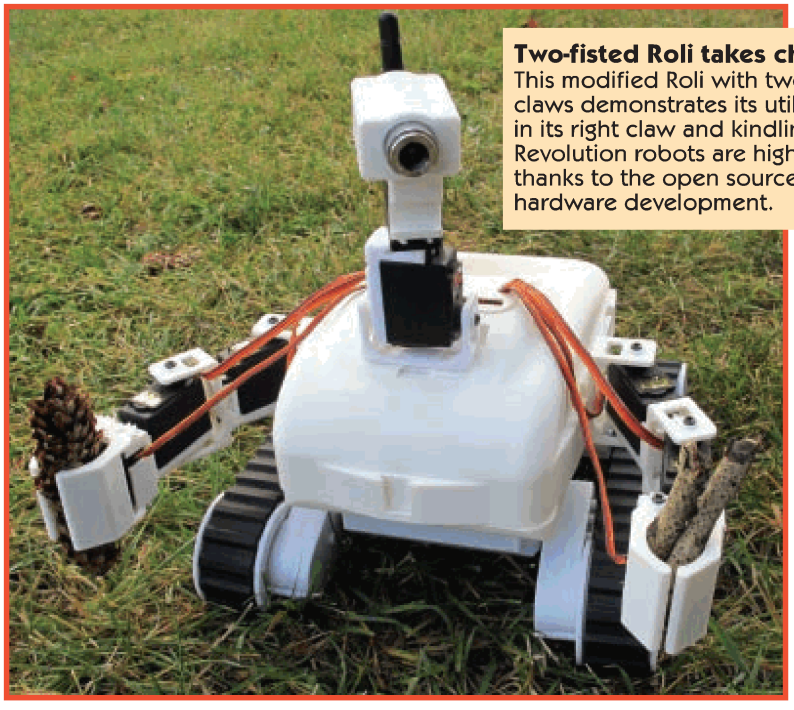
In response, Sures built a color wheel in software code. Now, roboticists can find and fine-tune the color they want to use. When the robot's camera sees the selected color, it can execute an associated script with the variable the roboticist has determined for that color — such as stopping or starting.



**Is this a Roli or a robot scorpion?**
This modified Roli's pincers and stinger make him look like a robotic scorpion. Fortunately, Roli is all bark and no bite — but watch out for those claws.



**Six straddles stump.**
EZ-Robot Revolution's "Six" hexapod robot straddles a tree stump in the wild. This hexapod is easy to program for sure six-footed walking and clear machine vision.



**Two-fisted Roli takes charge of the lawn.** This modified Roli with two arms and grasping claws demonstrates its utility with a pine cone in its right claw and kindling in its left. EZ-Robot Revolution robots are highly customizable thanks to the open source/crowd-sourced hardware development.

In just two years' time, Sures has produced 158 software releases with two to five such crowd-sourced capabilities built in each time. "The EZ-Builder software rolls it all together into a single, free download," says Sures. The software is compatible with other robots outside the EZ-Robot Revolution platform, as well.



**Six = four legs plus two arms with grasping claws.** Six shows off how highly customizable this platform is.

"We provide a bunch of starter, intermediate, and advanced apps to teach people how to start a robot off doing things, moving it into different positions," says Sures. EZ-Robot has over 200 tutorials available free for download to explain how to use the apps and to get the robot to do things like listen to your voice, follow colors, or chase a ball around a room (these are the basics). EZ-Robot also has apps to make the robots see things in augmented reality.

## The Results

"When 100 people had our circuit board, I saw one to two people creating something new and sharing it with everyone else. When 1,000 people had it, I saw 100 innovations. For example, one community member made an arm for grabbing from a walker to aid the disabled. Another added a camera with machine vision to a wheel chair so a disabled person could follow the person helping them as they walked in front of them," Sures explained.

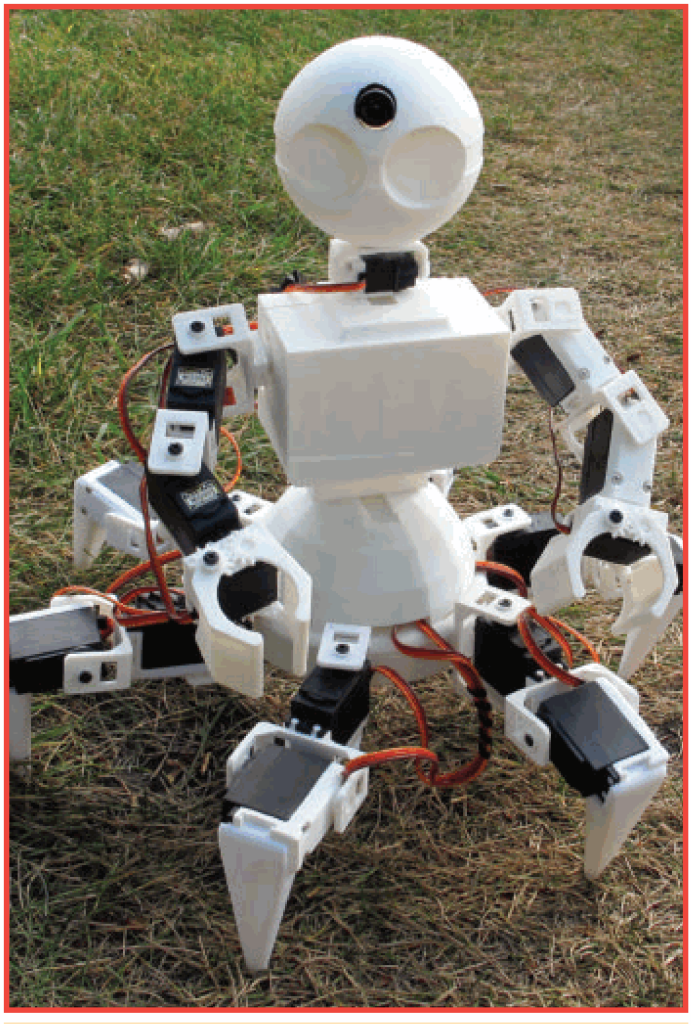
Another community member is working on enabling all 1,000 of his robots to talk to each other. He uploaded that capability to EZ-Cloud Variable Storage. "In our software, when you define the software's scope you can make it public – available to all modules on your program and everyone can access that. EZ-Builder means the entire world has access to it," Sures boasted.

Still another roboticist is working on solar robots using the Revolution platform. Another is making robots out of old toys using it. Even NASA is a customer of EZ-Robot Revolution.

One roboticist is using the innovative platform to create a humanoid robot that can pick up boxes based on bar code readings with the robot's camera and place them on a shelf. "Once this is a functional device, he can create a factory robot that will do the same. He has the ability to use the design files to make the robot full size for factory use," commented Sures.

## Conclusion

Due to the open nature of this platform, every EZ-Robot Revolution robot can be unique from the others. Every robot can also use what any other



**Is it Six or is it JD?**
JD's body, head, arms, and claws are connected to Six's base and legs. Half biped, half hexapod. Imagine what you could do with this robot and its combined capabilities.

builders have created and shared. "With EZ-Bits and EZ-Bits Designer, we now know what your robot was built with and how. The software shows you how to clip each piece together to build that same robot," Sures concluded. Now *that* is a community! SV

## Resources

DJ Sures' homepage
**www.dj-sures.com/default.aspx**

DJ Sures' EZ-Robot YouTube page
**www.youtube.com/user/aliencurv**

EZ-Robot introduction
**www.ez-robot.com/About/Get-To-Know-Us.aspx?id=2**

EZ-Robot Revolution
**www.ez-robot.com/Revolution**


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**WWW.VEXIQ.COM**

# ASK MR. ROBOTO

by Dennis Clark

Our resident expert on all things robotic is merely an email away.
**roboto@servomagazine.com**

**Tap into the sum of *all human knowledge* and get your questions answered here! From software algorithms to material selection, Mr. Roboto strives to meet you where you are — and what more would you expect from a complex service droid?**

Post comments on this article at **www.servomagazine.com/index.php/magazine/article/january2014_MrRoboto.**

As I write this article, the 2013 FIRST LEGO League (FLL) season is winding down for my team. The kids did well and scored in the Accomplished and Exemplary parts of the rubrics, as well as landing in the upper half of the robot scores at the competition tables. They suffered many setbacks and confusing moments when their robot stubbornly refused to do what it had been doing on our table back at the school. In this, they experienced what we robot hobbyists — and to some extent, robo-embedded engineers — experience all the time. That is, they discovered that sometimes our assumptions about our robot's environment are incorrect and we need to account for even more variables than we thought! It is a sobering discovery which always leads to a more robust design. The team got lucky on their last competition run when, magically, the robot started doing what they expected! Then, on the last task they ran, Dragon Bytes decided to solve the puzzle its own way and scored better than the kids had designed. There were many howls of laughter, knuckle-bumps, and high fives at that table! Call it an apocryphal tale if you wish, but sometimes you just get lucky!

I have a few interesting questions this month to answer, and some new boards to ponder the usefulness of ...

**Q.** I am trying to decide between analog and digital servos for my robot arm project. Is the extra cost of the digital servos worth it?

**— Tony**

**A.** To some extent, this answer will involve opinion. Since you are talking "analog vs. digital" servos, I assume you mean hobby servos like those used in RC planes and cars. My answer, therefore, is "it depends." The digital servos respond faster, hold better, and are more precise than analog servos. So, if precision and speed as well as constant torque (regardless of the setting) matter, then digital servos are what you want to use.

If this is a garage project for a dynamic art exhibit, I'd go for the cheaper analog servos since accuracy and repeatability are typically not what is required.

Another consideration is power. If you have lots of power reserves, the digitals are usable. If you have power limitations, then you should consider the analog servos. Digital servos typically are more power hungry than their analog brethren.

If you *really* want a good robot arm, you should consider the digital smart Dynamixel or Herkulex networkable servos. These servos will allow you to get positional feedback as well as current, load, and temperature. They can be addressed individually and talk back to their controller.

**Q.** My quadcopter goes through lithium-ion batteries like crazy, and my charger can't keep up. What should I look for in a fast lithium-ion charger that is affordable, say, less than $100?

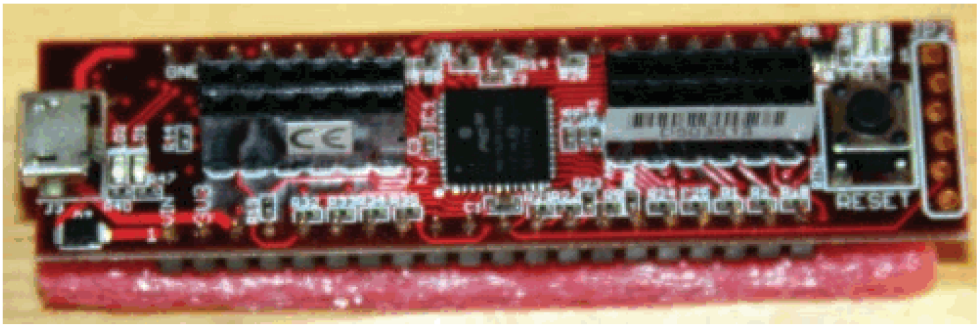
**— Marcus**

**A.** Again, this question relies somewhat upon opinion. I have used a few *really* cheap chargers (ones that are under US $40) and they have either let me down or left me "underwhelmed." There are two multi-chargers that I have been very pleased with, however: the Duratrax Intellipeak ICE and the Hitec X4 DC multicharger.

The Hitec X4 is well above your $100 limit, but the Hitec AC/DC X1 charger costs about $62US at a number of shops. I trust that charger. The Duratrax ICE DC charger is under $90US.

Both of these chargers will handle just about every battery type there is, and will charge, discharge, and discharge/charge cycle. (The latter of which is used to find out how robust your battery is.)

Figure 1.



No doubt there are other good chargers out there for your money, but you asked *me* and I have tried quite a few and settled on these two as worth their money.

If you can spring for the Hitec X4, you'll be content for life with its ability to charge four completely different batteries at the same time. This is very handy at a robot competition! Regardless, the two front-runners (in my opinion) will make you very happy!

**Q.** I'm working on a 3D printer kit and noticed it uses an inexpensive thermistor sensor to track the temperature of the head. Would a solid-state temperature sensor provide a smoother control? If so, which sensor would you recommend?

**— Timothy**

**A.** The answer to your first question is no. A solid-state solution will not give you what you want. The reason that I say this is that these "single chip" solutions that you talk to with I²C or SPI are not as accurate as a thermistor that is affixed directly to the surface that you are going to measure.

A thermistor will be far more accurate if your control system is using the correct transfer equations or Steinhart-Hart parameters to calculate the temperature. The thermistor will also typically have a much lower thermal mass and will track temperatures more quickly than a solid-state solution will.

I have used both solutions, but for different applications. I use a thermistor with precision amplifier components and Steinhart-Hart equations to calculate the precise temperature of water in a sensor. I use a solid-state I²C temperature monitor soldered to a controller board to tell me the approximate temperature of my printed circuit board (PCB) in its enclosure.

The former needs tight precision (like your 3D printer head application); the latter just needs reasonable accuracy to let me know when my system is beginning to overheat. You'll want to use the thermistor. Make sure that it is solidly attached to the print-head surface with some thermal paste.

Now for something completely different ...

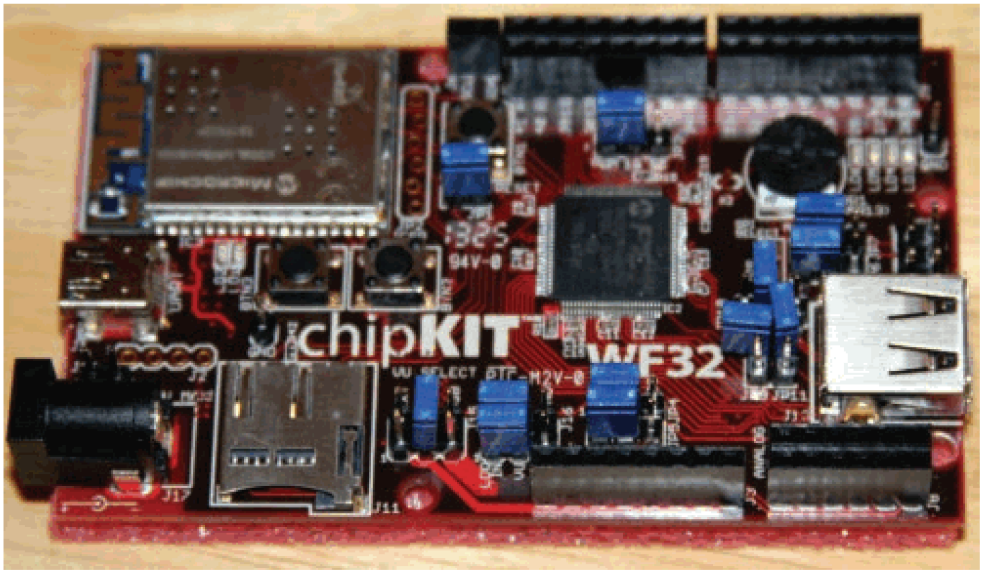
Recently, I came across a couple of additions to the Digilent chipKIT line that readers might be interested in. The first addition is the chipKIT CMOD (**Figure 1**). This small board has a PIC32MX150F128D 32-bit microcontroller on it running at 40 MHz. This is only half the speed of Digilent's usual chipKIT controller boards. I'm not sure why they clocked it down ... perhaps to reduce power?

This board is intended to go into smaller projects since it's only 2 cm x 7 cm. The physical size is the only thing small about it though, if you are used to using Arduino boards. The CMOD has 128K of program space and 32K of RAM, plus runs the Arduino compatible MPIDE version of the Arduino environment.

As my readers know, I'm very fond of the chipKIT series boards



Figure 2.




because I can use the MPIDE Arduino compatible IDE to quickly lash up projects. Many Arduino sketches run unmodified on chipKIT boards; others require small changes because of the different architecture.

There are 33 available I/O lines, two hardware UARTs, and a USB programming connector. There are even two PMOD connectors for use with Digilent's huge collection of PMOD options. At $29, it isn't the cheapest tiny Arduino out there, but it is the most powerful!

The second new chipKIT board is the WF32 chipKIT board. The WF32 runs the PIC32MX695F512L 32-bit microcontroller with 512K of Flash program space and 128K RAM at 80 MHz. It has a USB OTG connector, Wi-Fi module, uSD card slot, 43 I/O lines, and – you get the picture – lots of stuff. The board is slightly smaller than their chipKIT MAX32 board (see **Figure 2**) but has nearly as much capability as the Wi-Fi board stack comprised of a Digilent UNO32/Wi-Fi Shield/Basic I/O Shield combination (**Figure 3**).

This looks like the board to use for a "roll your own" wireless controller using the Digilent Wi-Fi web server stack that I talked about back in my November 2012 column. I'm going to see if it will run on this board with minimal changes.

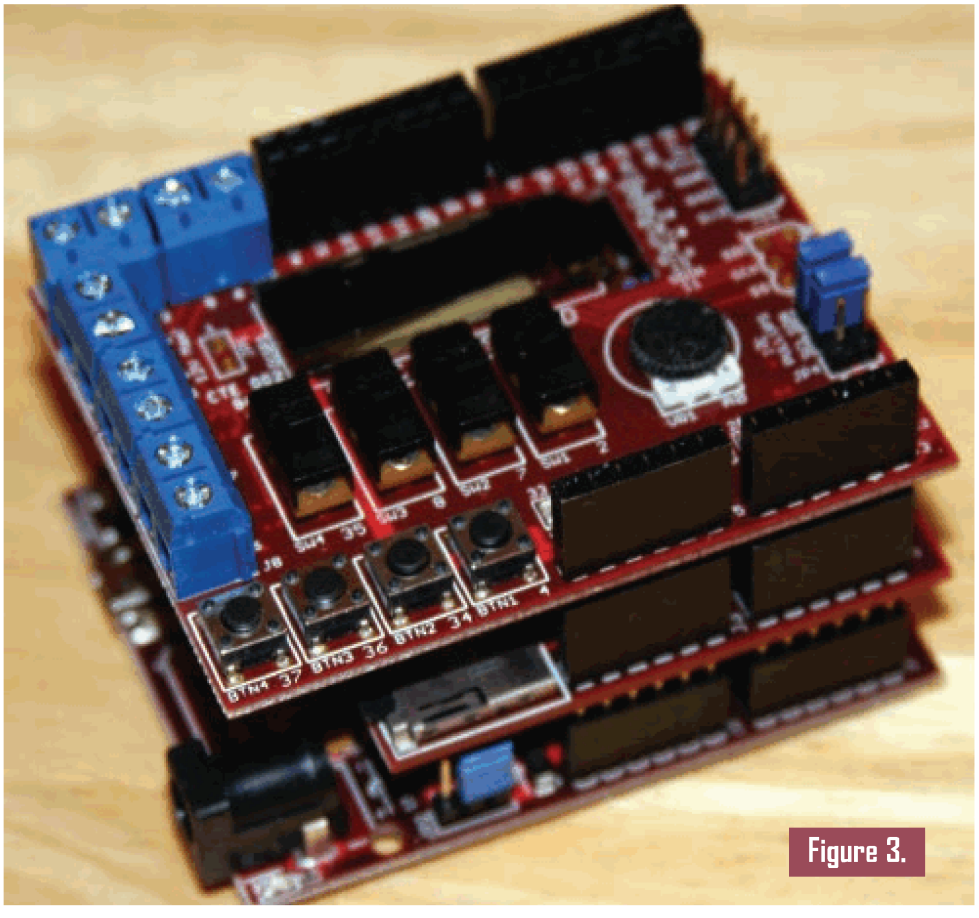


Figure 3.

This board is more expensive than the typical Arduino at $69, but for that you get a TON of program and data memory, uSD card, Wi-Fi module, and a USB OTG connection, for whatever you can think of.

The MPIDE that these boards use for Arduino compatibility is fully open source and is under continual development at Rutgers University and Digilent. I may be talking about these boards more in the future (as soon as I get the time!).

Well, that's it for another Mr. Roboto. I hope you learned something that you needed to know or were inspired to go out and try something new. As usual, if you have any questions about robotics, please send them to roboto@servomagazine.com and I'll do my best to answer them. Until next month, keep building robots!! SV

# Make The World Your Lab

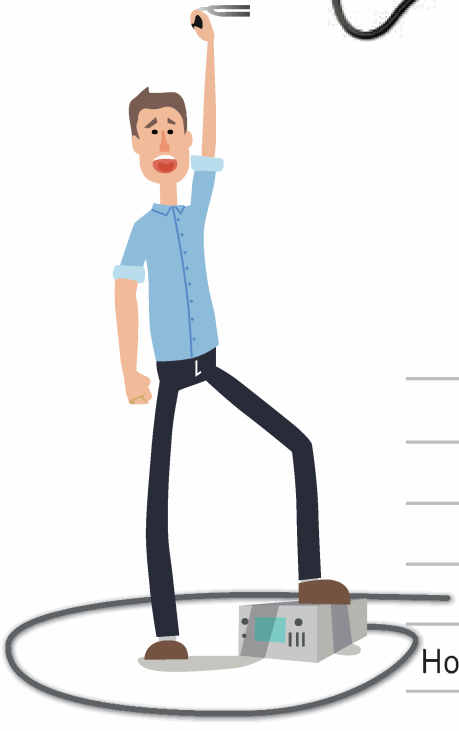
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# EVENTS

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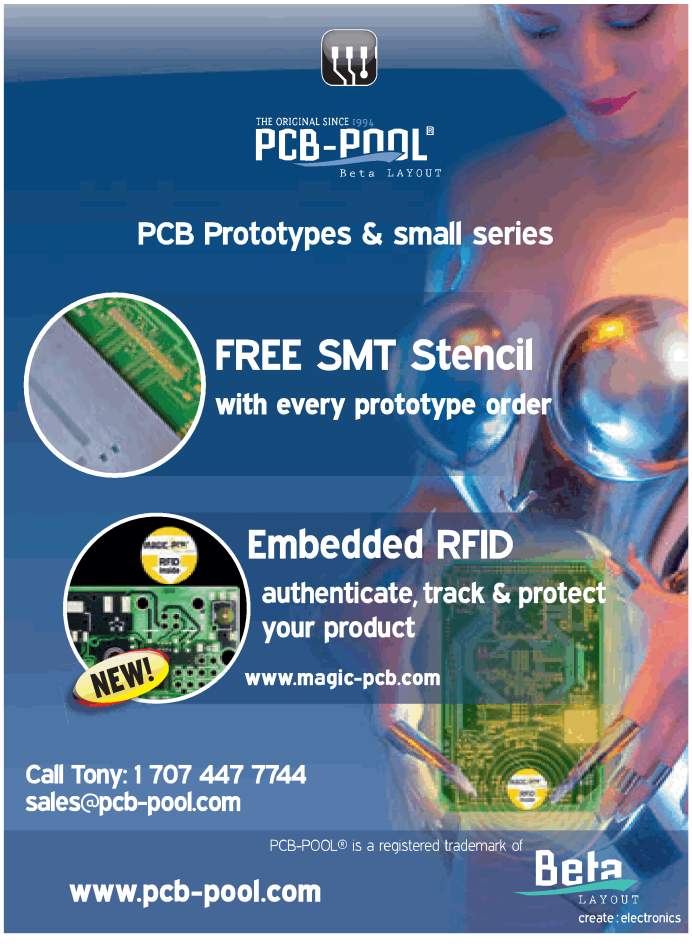
Know of any robot competitions I've missed? Is your local school or robot group planning a contest? Send an email to steve@ncc.com and tell me about it. Be sure to include the date and location of your contest. If you have a website with contest info, send along the URL as well, so we can tell everyone else about it.

For last-minute updates and changes, you can always find the most recent version of the Robot Competition FAQ at Robots.net: **http://robots.net/rcfaq.html**.

**— R. Steven Rainwater**

## JANUARY

**3-5** **Techfest**
*Indian Institute of Technology, Bombay, India*
University level competition for autonomous robots including events like the International Robotics Challenge, Robotron, and Code Master.
**www.techfest.org**




**22-23** **Singapore Robotic Games**
*Republic of Singapore*
A wide range of events for autonomous robots including Picomouse, Sumo, robot soccer, wall climbing, pole balancing, underwater robots, legged robot marathon, Robot Colony, and an event for humanoid robots.
**http://guppy.mpe.nus.edu.sg/srg**

**23-26** **ION Autonomous Snowplow Competition**
*St. Paul, MN*
Autonomous snowplow robots compete to remove snow on a designated path.
**www.autosnowplow.com**

**23** **Powered by Sun**
*Ostrava, Czech Republic*
Autonomous solar-powered robots compete in a race.
**http://napajenisluncem.vsb.cz/**

**24-25** **FIRST LEGO League of Central Europe**
*Paderborn, Germany*
FLL regional championship.
**www.hands-on-technology.de/en/firstlegoleague**

**31** **Robotix**
*IIT Khargpur, West Bengal, India*
Large tech competition for university students that includes a variety of robot-related events.
**www.robotix.in**

## FEBRUARY

**7-9** **Quark Roboficial**
*BITS Pilani KK Birla Goa Campus, Zuarinagar Goa, India*
2014 events haven't been announced yet, so check the website for updates!
**www.bits-quark.org/2014**

**14-16** **Motorama Robot Conflict**
*Harrisburg, PA*
Remote-controlled vehicles attempt to destroy each other.
**www.nerc.us**

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# NEW PRODUCTS

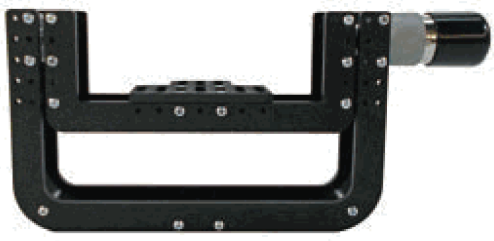
## Direct Drive Gearmotor Tilts

Derived from their servo driven cradle tilts, ServoCity now offers direct drive gearmotor cradle tilts. These cradle tilt systems are compatible with 3-12 VDC and 6-12 VDC gearmotors. The tilt framework is constructed of 1/4" ABS plastic side plates tied together using 6061 T6 aluminum Actobotics™ components. The height of the cradle is adjustable by moving the motor and bearing mounts up or down the outside cradle.

The inside height is also adjustable so that users can



properly center the mass of the object to be tilted about the axis of rotation. The camera plate has numerous 1/4" width slots so the mass of the object to be tilted in the



forward and aft direction can be balanced.

There are two models available: The 4" cradle is designed for cameras with a body width of 4" or less, while the 6" cradle offers a solution for larger cameras with a width of 6" or less. Both systems are rated for cameras up to three pounds.

These open loop tilts are an excellent choice for photographers and videographers using small video cameras or still cameras. To vary the speed of the tilt system, a speed controller can be utilized. The direct drive gearmotor cradle tilts can be mounted to other Actobotics components that utilize the .770" or 1.50" hub pattern with the included 6-32 x 1/4" pan head screws.

These tilts can be configured in the overhead or underslung position. The inside cradle has no range limitation (it can rotate a full 360 degrees). The tilt systems come in kit form, and step by step instructional assembly videos can be found on ServoCity's website. They are priced at $39.99 for the 4" tilt and $49.99 for the 6" tilt.

For further information, please contact:

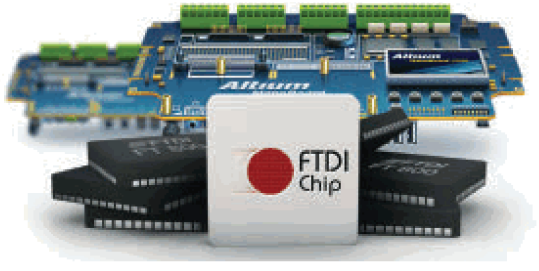
**ServoCity** Website: **www.servocity.com**

## Board Design Support for Embedded Video Engine Chips

Altium Limited has released new printed circuit board (PCB) design content supporting the FTDI FT800 family of HMI solutions.

The FT800 family – with its revolutionary EVE (Embedded Video Engine) Technology – combines display, audio, and touch in a single chip. This optimized solution reduces board area, power, and BOM requirements making it a solution for Human Machine Interface (HMI).

By releasing board design content to support the FTDI FT800 family, Altium eliminates the need for engineers to spend time developing and validating PCB footprints, schematic symbols, and 3D component bodies for the FTDI components. The content release includes live supply chain




solutions providing an accurate picture of overall project BOM cost, and assisting in sourcing the components quickly.

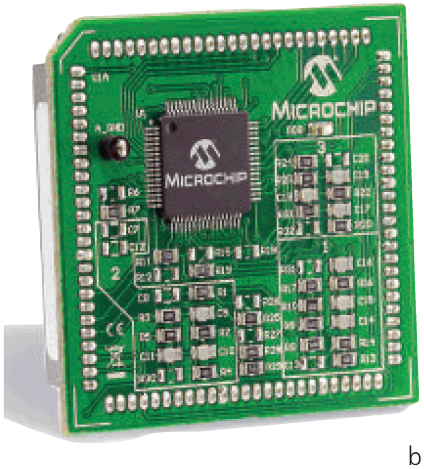
For further information, please contact:

**Altium Ltd./FTDI** Website: **www.ftdichip.com**

## Digital Signal Controllers

Microchip Technology, Inc., has announced a new family of dsPIC33 Digital Signal Controllers (DSCs): the dsPIC33EP512GM710 family. This is an expansion of Microchip's dsPIC DSC portfolio that adds higher levels of integration for motor control applications.

The new family of DSCs enables efficient dual motor control with 12 motor control PWM channels (six pairs), dual 12-bit ADCs, multiple 32-bit quadrature encoder interfaces, and two CAN modules. With this level of integration, the dsPIC33EP512GM710 family can independently control two motors with a single microcontroller for optimized system costs. This family can also serve as a communication hub for automotive or industrial applications to connect with multiple CAN busses.



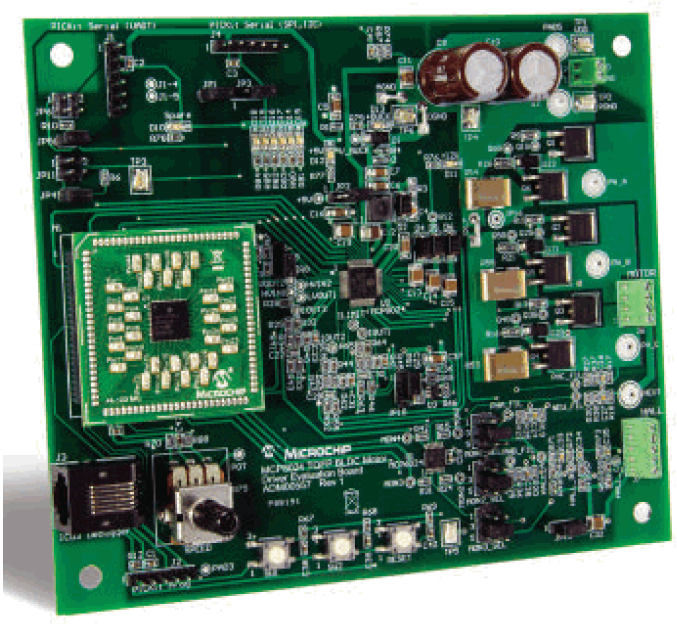

This family expands the existing dsPIC33EP families by supporting 512 KB Flash, 48 KB RAM, and four operational amplifiers (op-amps). Other features of this family include enhanced analog functionality with two independent ADC modules, configurable as 10-bit 1.1 Msps with four sample and holds or 12-bit 500 ksps with one sample and hold, supporting up to 49 channels. This analog integration enables advanced sensor applications that require multiple precision ADCs with several sample and holds, as well as the processing power of a DSP. The family also includes a Peripheral Trigger Generator (PTG) for scheduling complex high speed peripheral operations which saves software cycles and reduces firmware complexity.

The new dsPIC33EP512GM710 MCU family is available for sampling and volume production, starting at $2.63 each in volume.

## Motor Gate Driver

Also from Microchip Technology, Inc., is a new three-phase BLDC motor gate driver with power module: the MCP8024. This new device includes functions that power dsPIC DSCs and PICs with capabilities to drive six N-channel MOSFETs. Customers can implement improved performance and high robustness, providing increased efficiency and lowering system cost while reducing time to market.

The MCP8024 operates across a wide voltage range of 6V to 28V, and can withstand transient voltage up to 48V. The device provides high-integration analog such as three current-sensing operational amplifiers, an over-current comparator, MOSFET drivers, and a bidirectional




communication interface for a complete motor system design.

The configurable driver dead-time management, driver blanking-time control, and Over-Current Limit (OCL) for external MOSFETs offer a significant increase in flexibility. The adjustable step-down DC-to-DC converter powers a broad range of microcontrollers, with the efficiency benefits of a switch-mode power supply. Additionally, the wide operating temperature range from -40°C to +150°C (H-temp) allows the MCP8024 to be utilized in harsh environments.

The MCP8024 is available in thermally enhanced 40-pin QFN 5 mm x 5 mm and 48-pin TQFP 7 mm x 7 mm packages. The MCP8024 is well suited for a broad range of applications including fans, motion control, and robotics, among others.

The MCP8024 is available now for $2.61 each in volume.

For further information, please contact:

**Microchip Technology, Inc.**
Website: **www.microchip.com**

## Easy to Assemble Prototyping Boards

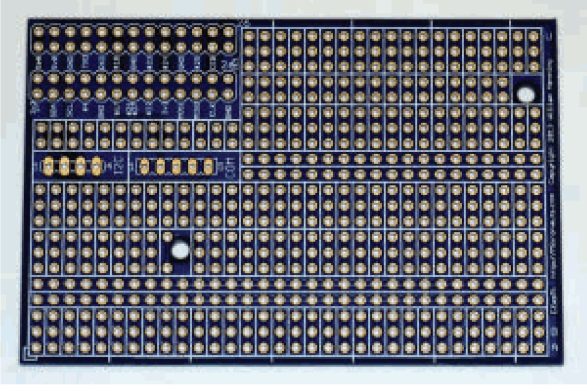
Adding to their existing line of prototyping and development boards, Mikronauts has launched the "Easy to Assemble" (EZas) series of prototyping boards.

All boards in the EZas line are silk-screened on both sides such that power and signal buses are highlighted, taking the guesswork out of finding the signals under the solder mask. EZas boards are designed to minimize the

need for jumper wires by careful component placement, and were specifically designed to be easy to prototype with servo headers and screw terminals. Educational users in particular will find the clear silk-screening helpful in teaching environments.

All of the EZas prototyping boards are high quality FR4, ROHS, lead free gold immersion (ENIG) boards.The first five products in the EZas line are described below.

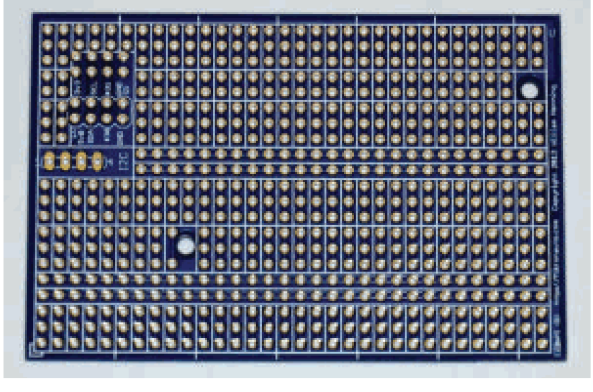
**EZasPi 85 mm x 56 mm**



Designed specifically for the Raspberry Pi and the educational market. Features include:

- Pi connector labeled on both sides
- Pi mounting holes
- Extra large prototyping area
- Servo and screw terminal friendly
- Mikronauts EZas silk-screening
- Mikronauts I²C header pads
- Mikronauts COM header pads
- Stacking headers available

**EZasPI (B) 85 mm x 56 mm**

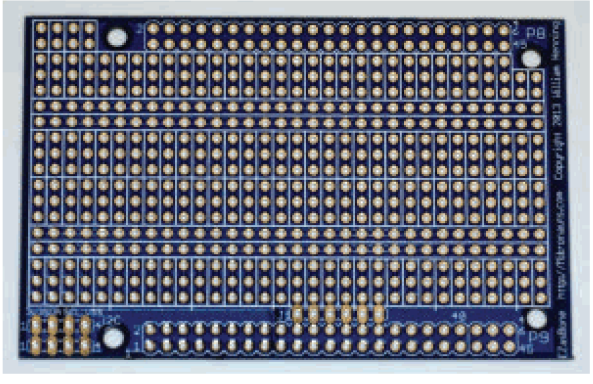


Designed specifically to take advantage of the extra GPIO provided by Rev.2 Raspberry Pis. Features include:

- Pi connector labeled on both sides
- Pi mounting holes
- Extra large prototyping area
- Servo and screw terminal friendly
- Mikronauts EZas silk-screening
- Mikronauts I²C header pads
- Stacking headers available

The Mikronauts EZasPi and EZasPI (B) boards are the first prototyping boards with mounting holes above the Raspberry Pi test mount holes, allowing them to be securely attached to the Pi with common M3-18 mm standoffs.

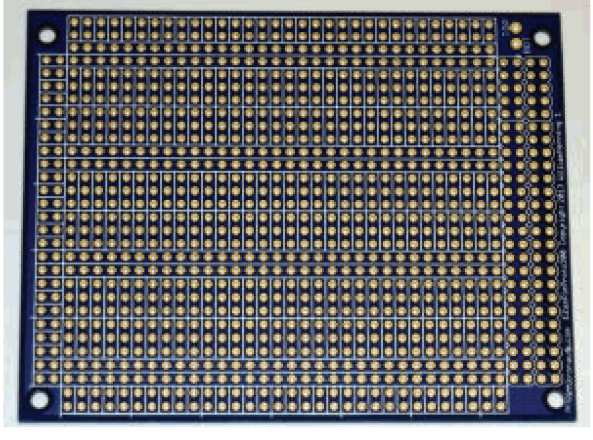
**EZasBone 86 mm x 54 mm**



Designed for the Beagle Bone Black development board. EZasBone provides more than twice the prototyping area of competing bussed prototyping boards and also features:

- BeagleBone mounting holes
- Servo and screw terminal friendly
- Mikronauts EZas silk-screening
- Dual Mikronauts I²C header pads
- Black soldermask boards available
- Stacking headers available

**EZasPieProto300 101 mm x 79 mm**

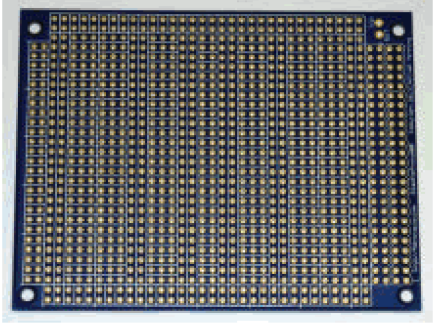


Inspired by EZasPI, the large 3.10" x 4.00" prototyping board is designed to accept a large number of 0.300" DIP packages.

EZasPieProto300 is designed to be general-purpose, and accomodates up to a 2x25 connector on the right edge. It can be used as an extra large prototyping board for any development board from any manufacturer. Features include:

- Servo and screw terminal friendly
- Mikronauts EZas silk-screening
- Stacks with previous Mikronauts boards and some Parallax boards

**EZasPieProto600 101 mm x 79 mm**



Also inspired by EZasPi, EZasPieProto600 was designed to support utilizing a very large number of servo headers with 40-pin DIP packages. It is designed as a general-purpose prototyping board for 600 mil DIP packages, and also accomodates up to a 2x25 header to a development board. Features include:

- Servo and screw terminal friendly
- Mikronauts EZas silk screening
- Stacks with previous Mikronauts boards and some Parallax boards

Quantity pricing for the EZasPi, EZasPi (B), EZasBone, EZasPieProto300, and EZasPieProto600 is available for distributors and educational organizations. For further information, please contact:

**Mikronauts** Website: www.mikronauts.com













## BOT TOSS

The iRobot 110 FirstLook is a small, light, throwable robot that provides hasty situational awareness, performs persistent observation, and investigates confined spaces.

Weighing about five pounds, FirstLook is ideal for clearing buildings, raids, and other close-in scenarios.

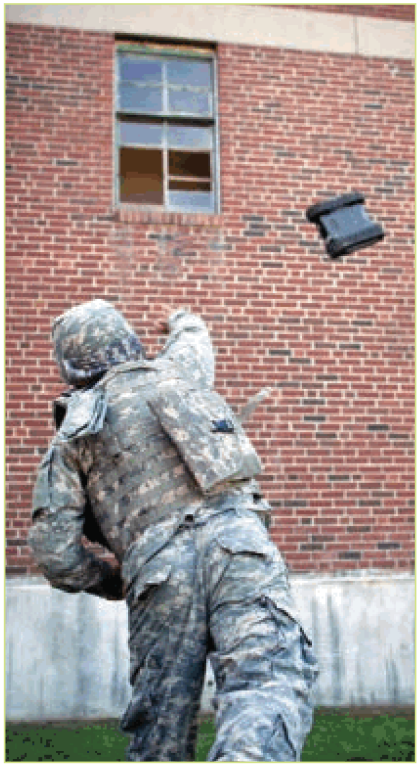
The robot can survive 16 foot drops onto concrete and is waterproof to three feet. It's 10 inches long, nine inches wide, and four inches tall. Powered by iRobot Aware 2 robot intelligence software, the operator control unit includes an integrated radio, battery, and joystick.





http://spectrum.ieee.org/automaton/robotics/robotics-hardware/video-friday-robokind-gets-kickstarted-and-firstlook-gets-armed

www.irobot.com/us/learn/defense/firstlook.aspx





## TAIL TALE

Here's a new implementation of an actuated tail that makes for one seriously maneuverable robot car.

The robot is called Dima (a name derived from a Sotho word that means "flash of lightning") and it was deliberately designed to be able to achieve high speeds with a high center of mass — a combination that works best (or only) when driving in straight lines. Turning at any speed that you might charitably call exciting leads to an immediate toppling over, but the addition of an actuated tail that can swing in the roll axis of the robot can effectively keep it stable.

This is a bit different from other tail-assisted turns because, in this case, the tail is being used to counteract the torque that the robot generates while turning, rather than being used to generate torque to turn the robot. Also, the tail is being turned in a roll axis instead of a yaw axis — an idea the researchers got after watching how a cheetah's tail moves when it makes high-speed turns.

After a bunch of experiments with both tail-less and tailed versions of Dima, results showed that the addition of the actuated tail allowed the robot to make stable turns at over twice the speed that it would be able to otherwise (7.5 m/s as opposed to 3.1 m/s).

**http://spectrum.ieee.org/automaton/robotics/robotics-hardware/iros-2013-robot-cars-get-hyper-maneuverable-with-actuated-tails**



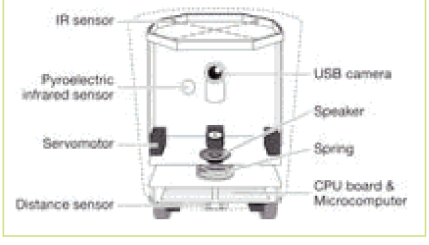


## TAKE OUT THE TRASHBOX

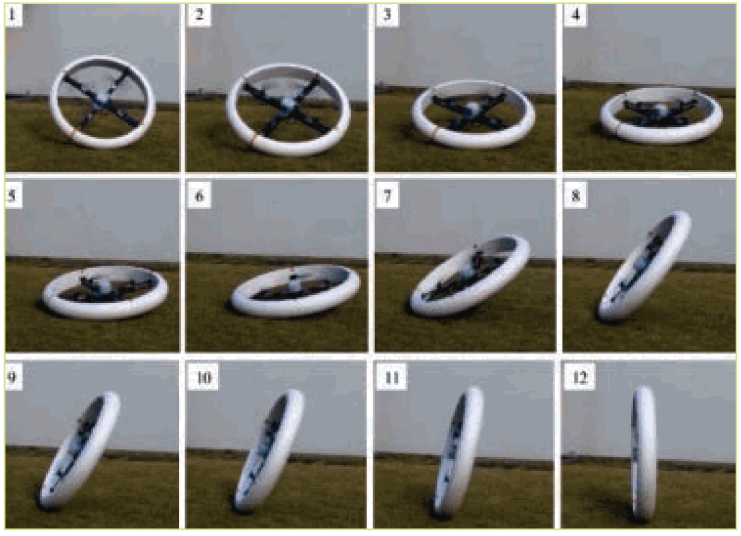
The idea behind Sociable Trashbox Robot is that you don't have to design a complex robot that can detect and pick up trash if you can just design a robot that will somehow *motivate* people to put trash into it.

The main purpose of this study is to investigate the effective social cues, behaviors, and other essential factors to facilitate children in their anticipation of the behavior of a sociable trash box robot (intentional stance). The STB uses interactive social cues and vocal interactions to build a social coupling with children in order to induce their assistance in collecting trash.








## DREAM RINGER

MUWA or "Multi-field Universal Wheel for Air-land Vehicle" (and also Japanese for "Dream Ring") is a quadrotor surrounded by a circular piece of foam that makes it capable of (among other things) balancing itself sideways like a wheel and rolling along the ground.

MUWA's secret to balancing tricks and wheel motion is that unlike most quadrotors, it's equipped with independently controllable variable pitch propellers (±20 degrees of pitch) that can direct thrust in two opposite directions, allowing it to stand up into a vertical position from the ground.

MUWA can roll, rotate, and even roll while maintaining an arbitrary angle relative to the ground.

There are a few reasons why these capabilities are relevant. First, it gives the quadrotor ways to move around without always having to expend energy flying. Second, by rolling, MUWA can squeeze through vertical gaps that it wouldn't be able to while flying horizontally. By getting MUWA to do things like rotate around a point on the ground while changing its angle (the researchers call it tornado motion), a Kinect sensor on the robot can rapidly build up a complete 3D map of its surroundings.

**http://spectrum.ieee.org/automaton/robotics/aerial-robots/iros-2013-quadrotor-wheel-can-fly-float-and-roll**

## ROBOT ROCK CLIMBER



JPL now has a microspine gripper system which uses hundreds of tiny little claws to grip rough surfaces. An upgraded version of their gripper integrated onto their LEMUR IIB robot turned it into the "world's first rock climbing robot."

Each one of these grippers relies on over 750 tiny little claws (all made by hand thanks to JPL summer interns) to latch onto the sort of rough surfaces that you're likely to find on other planets and asteroids. The grippers are particularly relevant to asteroids, since they offer a dependable (and reversible) way to grab onto surfaces even in microgravity.

**http://spectrum.ieee.org/automaton/robotics/military-robots/iros-2013-jpls-microspine-rock-climbing-robot**

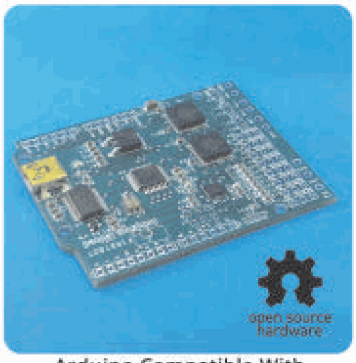
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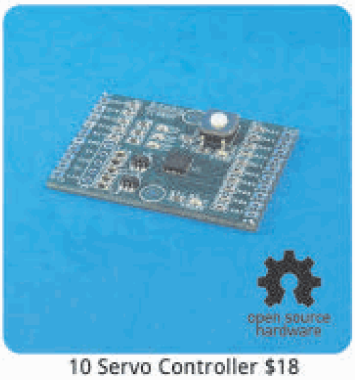
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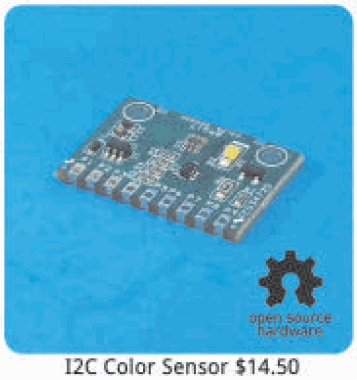

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10 Servo Controller $18



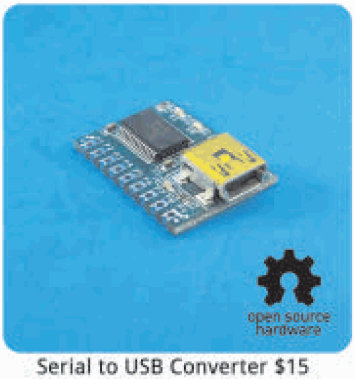

2-Motor 4-Servo Controller $25




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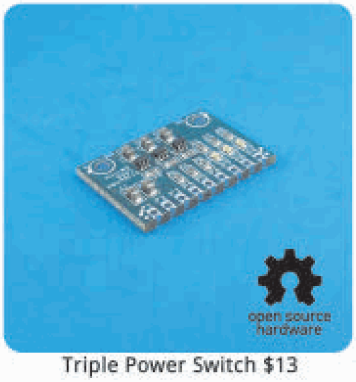

IR Object Detector $10



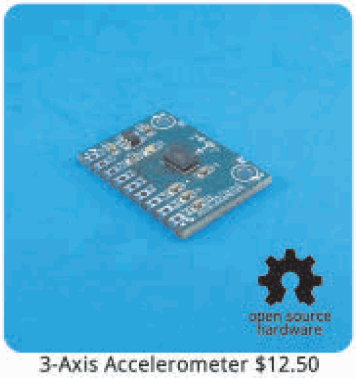

Serial to USB Converter $15



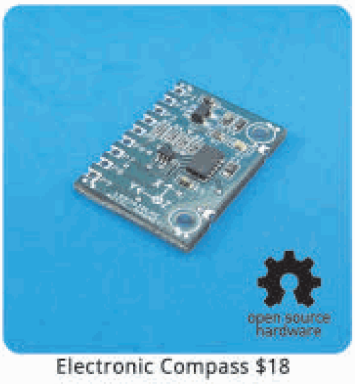

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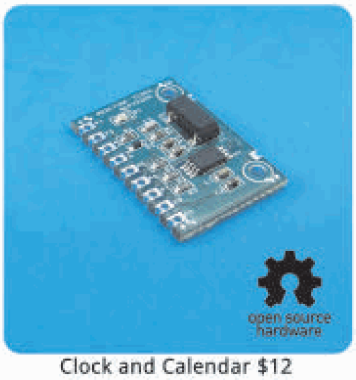

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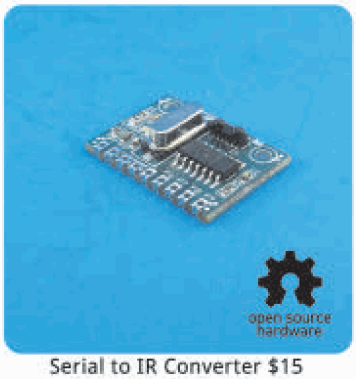

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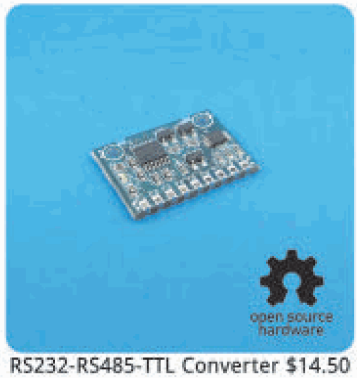



Serial to IR Converter $15

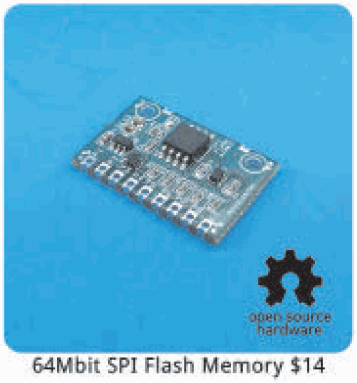
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## Featured This Month:


30 *BUILD REPORT: Isotelus Rex — Part 1*
**by Pete Smith**

34 *PARTS IS PARTS: Product Review: FingerTech Robotics tinyMixer*
**by Mike Jeffries**

35 *EVENT REPORT: The Adventures of Scary and Angry Bot*
**by Matt Spurk**

39 *EVENT REPORT: Franklin 2013 — Fall Fun in Philly*
**by Pete Smith**

43 *CARTOON*

44 *THEN AND NOW: A Decade Later with Alexander Rose*
**by Kevin Berry**


# BUILD REPORT: Isotelus Rex Part 1

● by Pete Smith

A weight class in combat robotics can be dominated — often for years — by one particular bot. Think of Super Megabyte or Last Rites in the top weight classes, and Totally Offensive and Killabyte in the Featherweights. These bots were the ones to be feared; the ones you didn't want to meet in the first round of a competition, but also the ones that you — and everyone else — wanted to beat!

The 12 lb Hobbyweights have had their champions, as well. The drum bot Solaris ruled the roost for years until its builder took up snowboarding. I too had my time in the sun with my horizontal blade spinner Surgical Strike, taking first place twice at Motorama and winning at RoboGames. That bot's reign ended when it met the current king of the hill, Cataclysm (**Figure 1**) at Motorama 2011. The drum bot took first place and repeated that performance with ease in 2013. It combines a well-designed and very solid titanium chassis,

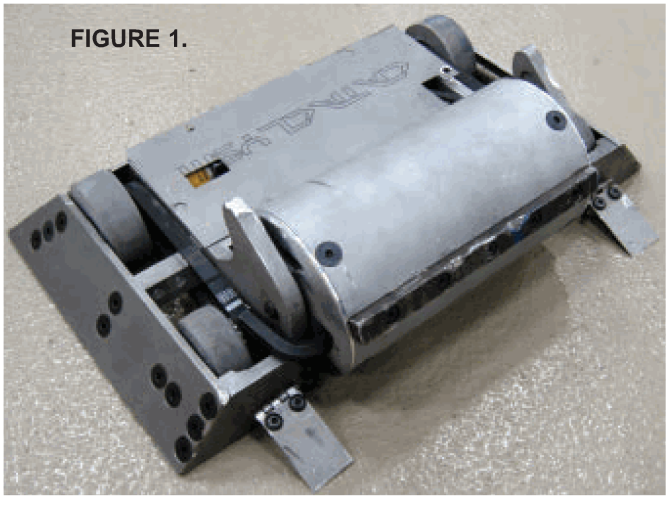
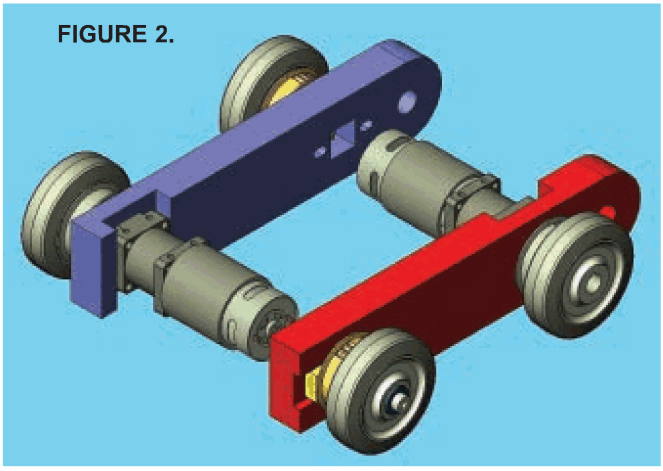
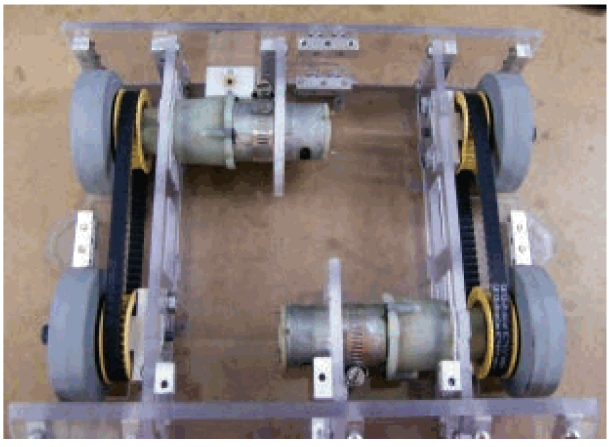


FIGURE 1.


FIGURE 2.


FIGURE 3.

good speed, and a big hitting drum.

So, how do you beat what is perhaps the ultimate drum bot? Well, since combat robotics is a game of rock, paper, scissors, and Cataclysm is the ultimate scissors, then what is needed is a better rock. I faced the same problem a few years back when Grande Tambor was dominating the Beetleweight class and the answer then was my wedge/brick Trilobite (**Figure 2**).

Trilobite can be fitted with a variety of wedges in order to match up to whatever is its opponent's weak point. It worked, with Trilobite winning its very first competition and defeating Grande Tambor a couple of times in the process.

So, the question is can I build a 12 lb version of my 30 lber? The first problem is that there is no equivalent motor for 12 lbers to the Kitbots' 1,000 RPM motors I use in Trilobite. The most obvious one to use is BaneBots P60 with RS-550, but if you use one per wheel the bot is forced to become excessively wide which just adds volume and weight. So, that leads to using only two motors and using a belt drive to drive the other wheels. I have used this configuration a couple of times before. My Hobbyweight wedge CheepShot 3.0 and my 30 lb Featherweight Xhilarating impaX used it with considerable success – including a National Championship for both in 2006.

The arrangement can be seen in **Figure 3**. A motor at the front drives the front wheel on that side and the rear wheel on the same side through a 5 mm HTD belt drive. Similarly, a motor at the back drives the wheels on the other side.

CheepShot 3.0 used cordless drill motors; performance was adequate but not scintillating. Its big brother Xhilarating impaX used a pair of Mini-EV motors (RS-800s?) with planetary gearboxes (**Figure 4**) that are no longer available. Performance with these motors was very good – even in a 30 lber.

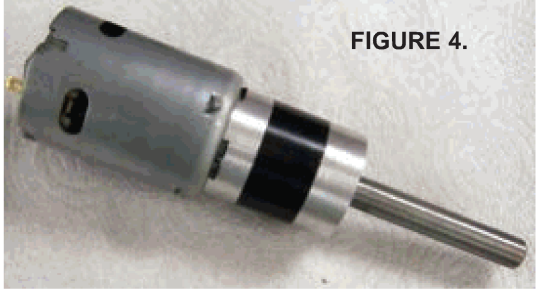
What I would like to do is use these more powerful motors in a 12 lb design. They proved very reliable in the Featherweight, but I only have a pair of the gearboxes and only one spare motor. BaneBots does a P60 gearbox with a RS-775 (**Figure 5**); if the design could take those as well, that would be a useful backup if the old motors ever fail.

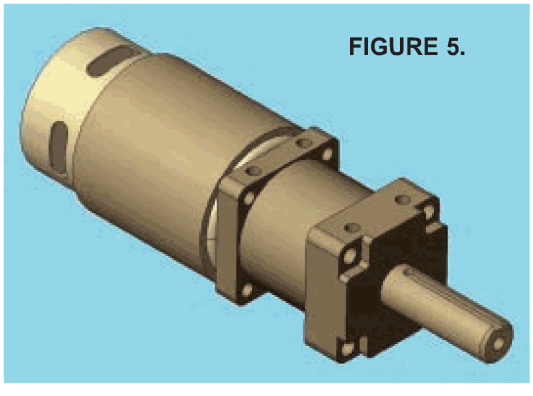
The design all starts in the CAD model. I used SolidWorks, but any good 3D CAD software would do. Trilobite uses 1/2" thick UHMW main chassis members, so I went with 1" on the new bot design.

It should be noted that scaling up or down a design from one weight class to another is not as easy as it would seem because strength goes up by a square rule, while weight goes up by a cube rule. So, in very general terms, a material twice as thick is four times as "strong," but if all the dimensions are doubled it's eight times as heavy!

I want the chassis rails to be four times as strong because it's in a weight class that's four times as heavy. However, I certainly can't afford for them to be eight times as heavy, so it's important to keep the bot as small as possible to keep the weight down.

The rails have two machined recesses (**Figure 6**) to allow the width of the bot to be kept to a minimum. The alternate motors fit the same recesses, as well (**Figure 7**); it can be seen that the mounting blocks for the


FIGURE 4.


FIGURE 5.

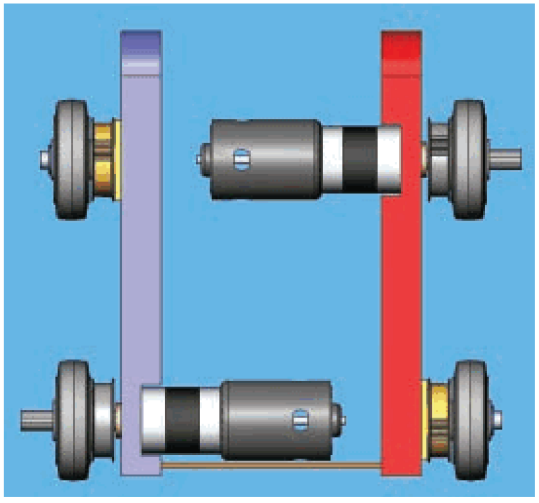


FIGURE 6.

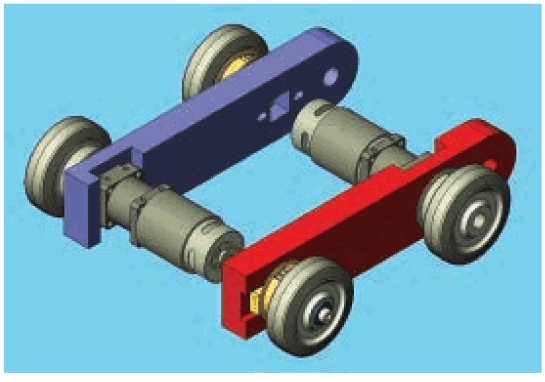


FIGURE 7.

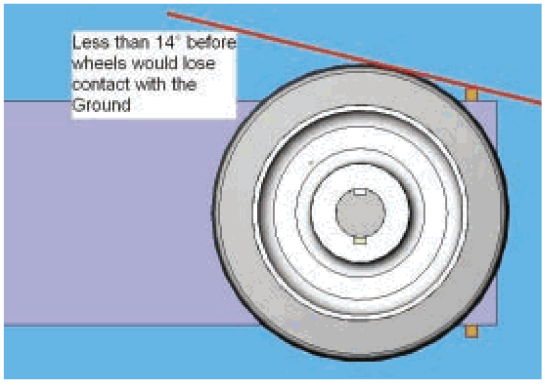



FIGURE 8.

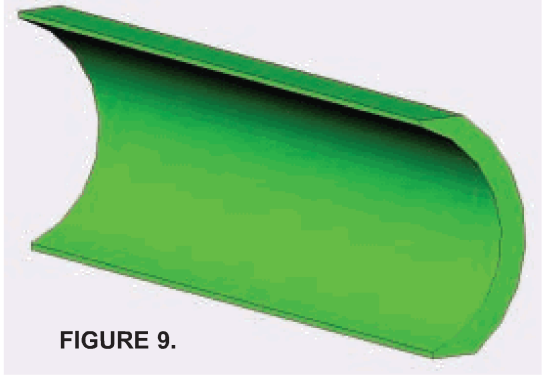


FIGURE 9.

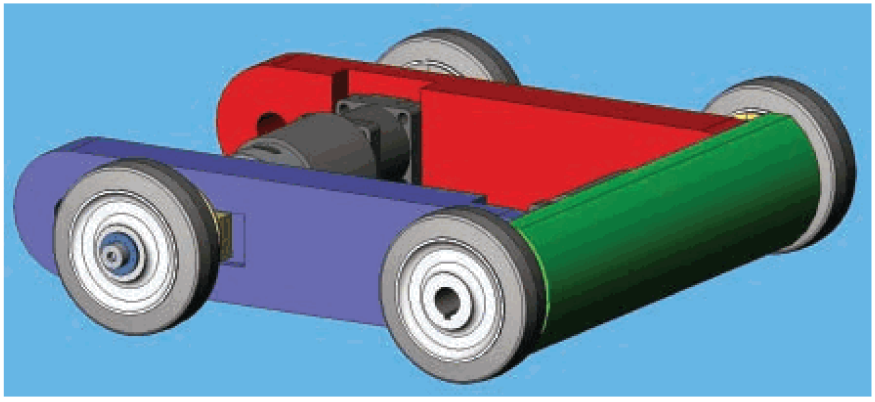


FIGURE 10.

drive wheels are also recessed so that the drive pulleys all line up correctly.

An Oilite bush is used where the 1/2" shafts of the motors pass through the chassis rails. This adds support to the shaft and means we do not need another bearing on the outer side of the wheel. I don't like to support shafts on the outer side as these bearings and their mountings would be very vulnerable to damage in a fight.

CheepShot 3.0 and Xhilarating impaX each had the same Achilles heel: If the nose of the bot was lifted — even a short distance — off the ground, the rear wheels would also lose contact and the bots would be pushed around too easily.

Trilobite's design got around that by ensuring the rear wheels are far enough back to always remain in contact with the ground. The diameter of the motors used in the new design are much bigger relative to the wheel size (3" wheels and 2" motors as opposed to the two 1/4" wheels with 1" motors) so that any vertical rear wall in the chassis means that even a 14° angle would result in the wheels losing traction (**Figure 8**).

That is not acceptable, so I needed to find a solution. That solution came in the form of two 3/4" diameter 1/4" wall thickness aluminum tubing. I could machine a section of the tubing to leave a curved wall (**Figure 9**) that can be screwed to the end of the main chassis rails (**Figure 10**). The bot will now have traction no matter how high the front end is pushed up.

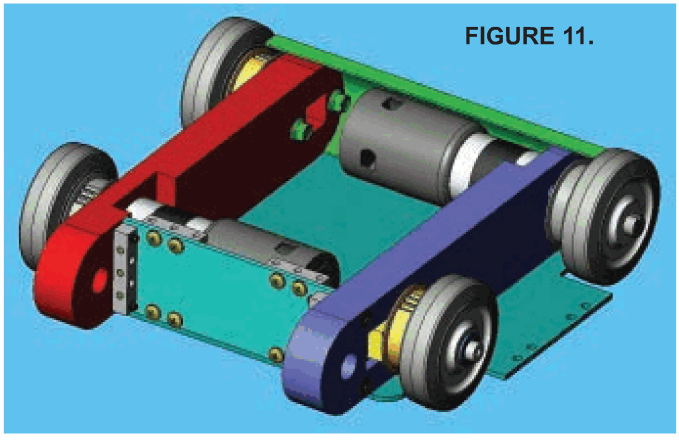
A 1/8" thick 7075 aluminum base plate is secured in place by Plastite screws; a similar thickness is used to make a front bulkhead (**Figure 11**). The latter is attached using medium Nutstrip and 10-24 machine screws. The top panel is the same as the bottom, and 3/8" UHMW side armor panels protect the wheels (**Figure 12**).

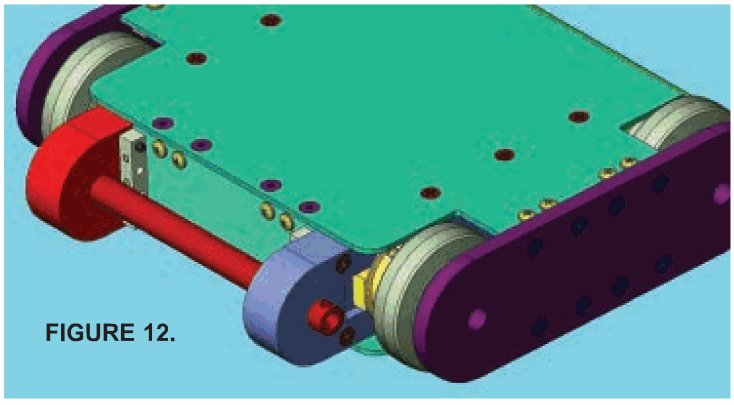
A 5/8" case hardened steel shaft is bored out to lighten it (I did this with success in the weapon drive shaft of Surgical Strike) and is used as the hinge pin for the wedges. The shaft will be retained in position with a couple of cotter pins.

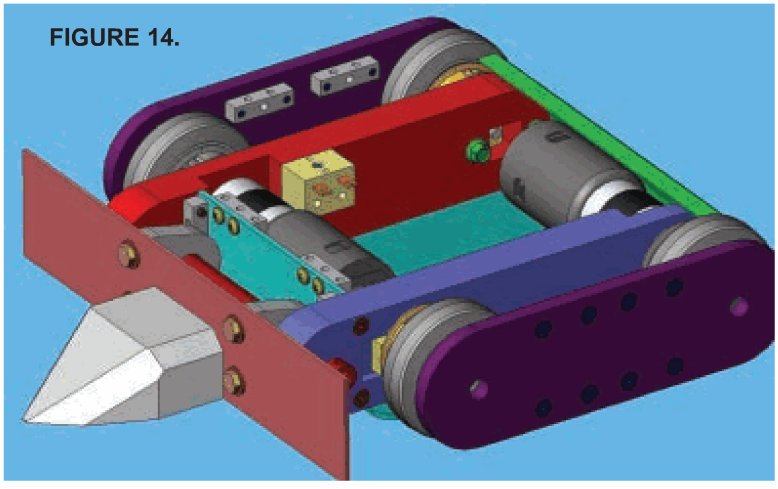
A scaled up version of Trilobite's "drum killer" wedge is made up of a titanium backplate, 7075 aluminum hinge brackets, and a UHMW "nose" (**Figure 13**). A Team Whyachi MS05 power switch is added to the interior (**Figure 14**).

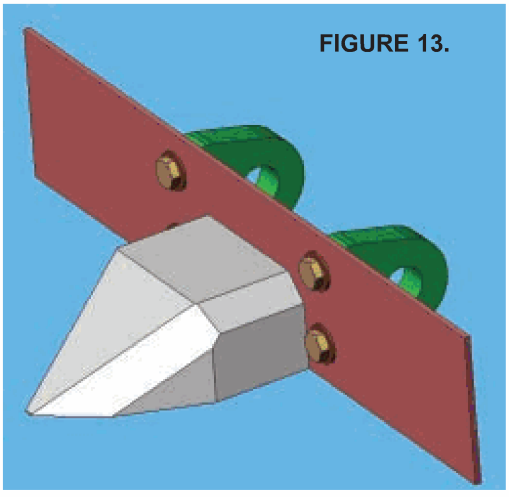
If space and weight are tight, the much smaller Fingertech Robotics power switch likely has a sufficient current rating for a couple of Mini-EVs or RS-775s.

With an initial design complete,


FIGURE 11.


FIGURE 12.

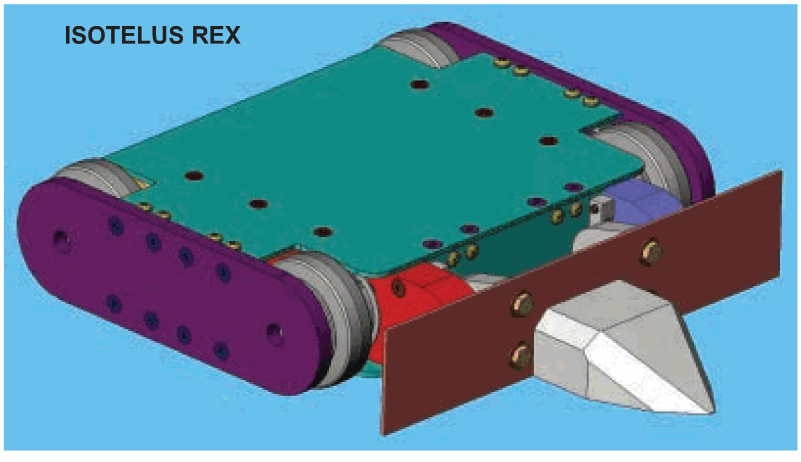

FIGURE 14.


FIGURE 13.

I then created a spreadsheet that included the number and weight of almost every part used in the bot. This is an important part of the design process and a quick glance at the spreadsheet (**Figure 15**) shows why. The design is 5 oz overweight when fitted with the bigger Mini-EVs.

Bringing the design to within the 12 lb weight limit will be the subject of Part 2.

So, what's the name of my new bot? Well, Isotelus Rex is the biggest Trilobite species yet discovered at over a yard long! My bot won't be quite *that* big, but hopefully opponents like Cataclysm will find it just as formidable. SV


ISOTELUS REX

| Description | Qty | Weight | Total weight |
|---|---|---|---|
| Right Wall | 1 | 0.68 | 0.68 |
| Left Wall | 1 | 0.68 | 0.68 |
| Top | 1 | 1.015 | 1.015 |
| bottom | 1 | 1.015 | 1.015 |
| Rear | 1 | 0.59 | 0.59 |
| Banebots P60 with 700 motor | 0 | 1.25 | 0 |
| WD40 gearbox with Mini EV | 2 | 1.9 | 3.8 |
| Driven wheel sets | 2 | 0.34 | 0.68 |
| Idler wheel sets | 2 | 0.27 | 0.54 |
| Belts | 2 | 0.0375 | 0.075 |
| Wedge axle | 1 | 0.45 | 0.45 |
| Wedge hinge | 2 | 0.132 | 0.264 |
| Front bulkhead | 1 | 0.15 | 0.15 |
| Side Armor | 2 | 0.3 | 0.6 |
| Wedge back Plate | 1 | 0.522 | 0.522 |
| Wedge Nose | 1 | 0.34 | 0.34 |
| 3 hole medium nutstrip | 12 | 0.02 | 0.24 |
| 4 hole medium nutstrip | 2 | 0.025 | 0.05 |
| 10-24 x 0.500 Pan head screws | 30 | 0.006 | 0.18 |
| 10-24 x 0.75 Flt Head screw | 16 | 0.0065 | 0.104 |
| 10-24 x 0.5 Flt Head screw | 8 | 0.005 | 0.04 |
| #10 x 0.500 Flt head Self tap | 18 | 0.0037 | 0.0666 |
| 10-24 x 1.5 Flt Hd screw | 4 | 0.0125 | 0.05 |
| QTR-20 x 0.750 Hex Head | 4 | 0.0153 | 0.0612 |
| QTR - Washer | 4 | 0.00345 | 0.0138 |
| QTR -20 x 1.5" pan head | 4 | 0.0225 | 0.09 |
| QTR - 20 Flange Head | 4 | 0.02189 | 0.08756 |
| M4 x 35mm | 8 | 0.007 | 0.056 |
| M5 x 40 flt head | 2 | 0.0123 | 0.0246 |
| Oilite Bushing | 2 | 0.03 | 0.06 |
| | | | |
| Batteries Turnigy nano-tech 1300mAh 6S1P | 1 | 0.47 | 0.47 |
| ESCs BotBitz 30AMP ESC | 2 | 0.14 | 0.28 |
| BEC | 1 | | |
| Power switch | 1 | 0.0625 | 0.0625 |
| | | | 13.33726 |

# PARTS IS PARTS: FingerTech Robotics tinyMixer

Product Review

● by Mike Jeffries



FingerTech Robotics has recently developed and produced a new channel mixer for use on robots in all weight classes. The tinyMixer weighs in at only 2 g and the main body has a footprint of 8.9 mm x 6.3 mm x 22 mm. It retails for $19.05CAD.

In the **photo**, the tinyMixer is shown with a tinyESC and a quarter. A mixer is a small device that can be placed inside your robot to allow you to combine two channels on a pistol grip or airplane style transmitter to alter how the controller interacts with your speed controllers.

In the case of a pistol grip style controller, this would allow you to use the throttle for the forward-reverse function on a tank/differential style drive robot and use the steering wheel for turning. Without a mixer, you would have the throttle control one side of the drive system and the wheel control the other side.

For an airplane style transmitter, you would use this to allow one stick to control both sides of the drive with up/down on the stick corresponding to forward/reverse, and left/right turning the robot to the left or right. Some airplane style transmitters can do the mixing on board, which is typically referred to as elevon or V-tail mixing.

Depending on the specific model of transmitter, the mix setting could result in not getting the full throttle travel or the need for several additional layers of settings to get full speed performance. An in-bot mixer provides a simple lightweight way of avoiding those issues.

In addition to the standard mixing functionality, the tinyMixer also has an invert switch which can be plugged into your transmitter to allow you to quickly and easily switch between normal and inverted driving. For invertible robots, this will make it much easier to drive your robot should it be flipped, as you won't have to deal with remembering that forward and reverse are swapped on an inverted robot.

The tinyMixer also has the option of disabling the mixing while maintaining the invert switch functionality, and autocalibrates its output to maximum transmitter input travel.

The market for mixers is fairly shallow right now with the primary competitors being the IMX1 from Robot Logic, the Digimix 3, and something in the range of half a dozen variants on the same basic cheaper imported mixer.

The IMX1 provides mixing, an invert switch, and the option to bypass the mixing feature, while retaining invert functionality. The IMX1 is priced at $39.99US and uses a much larger board. So, while it has many of the same capabilities, those features come at a higher price with a larger footprint.

The Digimix 3 replaces the Digimix 2 which was similar in size to the tinyMixer but lacked the invert switch. The Digimix 3 is a new version of the mixer that adds an invert switch. Weighing 25 g and costing $49.99US, the Digimix 3 is the most expensive option without gaining any real functionality. While smaller than the IMX1, the Digimix 3 takes up about three times as much space as the tinyMixer.

The cheaper imported mixers are all fairly similar and typically only offer mixing functionality. These low cost mixers also frequently have issues with failsafe behavior in robotic applications without an obvious way to determine if it will or won't have the issue. They're small, cheap, and generally will work, but most combat events will require some failsafe functionality which will mean they aren't appropriate for a fighting robot.

The tinyMixer is a great option if you're in a situation where you either want or need to use an in-robot mixing device. The low cost, light weight, and small size mean it will be an easy option for an extremely wide range of designs. SV

# EVENT REPORT:
## The Adventures of Scary and Angry Bot

● by Matt Spurk

Last month, I did a brief report about how my two sons and I built their first "real" combat robots — "Angry Bot" and "Scary." This month, I want to discuss how they did in their matches. You may be a bit surprised by the result.

Our first event with these robots was going to be the Battle at Maker Faire, which took place in conjunction with the Orlando Mini Maker Faire at the Orlando Science Center, in Albuquerque, NM (Just kidding. It was in Orlando, FL).

Saturday was the big robot fight. Both boys were very excited. Daddy was very nervous. We got to the event and I was already exhausted. The emotional fatigue of being proud, nervous, excited, and anxious easily took 10 years off my life.

We got to the space, and I started getting everything ready for the event. The boys went around and checked out all the robots that "weren't as good as theirs." They especially enjoyed the robots that "they were going to smash into the pit."

The two of them barely spoke to anyone during check-in at the Faire, but they were talking the ears off the other builders. We got both of the boy's bots ready and took them over for weigh-in. Ethan's Scary came in at 15.3 oz and Cayden's Angry Bot came in at 15.6 oz. Great! We didn't need to worry about drilling holes in our pretty robots.

We let the boys do a little sparring in the big arena and practice driving around the much larger 8' x 8' SECR-FL Insect ring. They had fun, and got a little more time on the sticks. We put both bots back on the charger to top them off.

The boys went out to explore the Faire, while I stayed and finished troubleshooting electrical problems in my bot.

### Fight 1: Angry Bot vs. Cheese Wedge

Cayden was the first of us to get to fight. He had a very competitive fight going, but got flipped over onto his back and got stuck. I knew this was a problem, but in my haste to get the bot ready with the new spark gearmotors I forgot to cut the back supports so it would flip back onto its wheels. The driver of Cheese Wedge was an amazing sport. He pushed Cayden's robot back over, so he was able to continue fighting.

It was a pretty good match. Cayden definitely needed a few more weeks of practice, but overall it was



**Photo 1: Angry Bot delivering Cheesie Wedge to the pit as time expires.**



**Photo 2: Ethan and Scary preparing for fight #1 against One Night.**

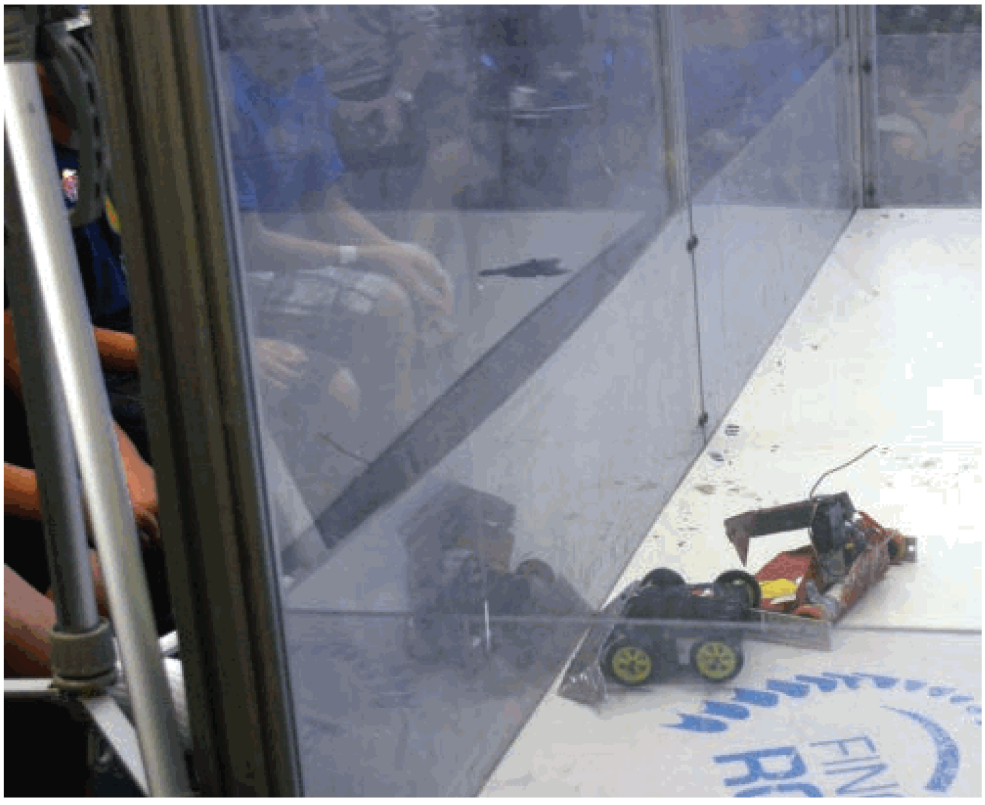


**Photo 3: Angry Bot has HooDoo on the ropes.**



**Photo 4: Scary gets revenge on HooDoo.**

pretty good. In the last five seconds of the match, Cayden snagged Cheese Wedge in the pan and drove him to the pit. Time expired and Cheese Wedge was still in pan.

Since the fight was over, Cayden stopped driving his robot (like I told him), so Cheese Wedge sat there teetering on the edge of the pit. I told Cayden to raise his pincher and Cheese Wedge fell into the pit. The contest went to a judge's decision, and Cayden won a very *very* generous audience vote. Angry Bot: 1-0.

I want to say thanks to Cheese Wedge. He gave that win to Cayden, and was a true gentleman.

## Fight 2: Scary vs. One Night

One Night was nearly a clone to Cheese Wedge. Scary and Cheese Wedge engaged in a traditional wedge vs. wedge battle, but with very untraditional driving from Ethan. It was a hilarious fight. I kept telling him to spin around and face the other robot, which resulted in about five spins and then pointing in roughly the same direction he started from.

The two wedges got into each other a couple times, and ultimately Scary got flipped onto his back. I tried to advise Ethan as he drifted towards the pit to move away, but I got the controls backward in my head and told him how to drive right into the pit. Unfortunately, he actually listened to me and dived right into the pit. This was a loss for Scary.

After watching the post fight video, I noticed that One Night actually had one bum wheel and was about to be counted out. I should have just told Ethan to take his hands off the controls, but I didn't notice that during the fight. Scary: 0-1.

## Fight 3: Angry Bot vs. Piranha

Angry Bot drew a spinner. Before the event, Cayden said he was just going to forfeit if he had to face a spinner. Luckily, his mother and I were able to convince him that he didn't need to worry about spinners, because his bot had really tough armor.

Piranha was a vertical bar spinner with a small diameter steel bar. Cayden apparently felt the best way to win this fight was to drive backwards into Piranha's blade. The strategy seemed to work surprisingly

well because Piranha wasn't able to get a good bite into the curved rear armor. He did put some sizeable dings into the front armor, but because he was in the pan he wasn't able to flip Angry.

This fight went back and forth. Cayden got in a couple of good clamps. Piranha had a couple of hits, but nothing that really did any significant damage. This fight also went to the audience decision and Cayden won again in a close ruling. Angry Bot: 2-0.

## Fight 4: Scary vs. Piranha

The downside of having a three and a half year old for a robot driver is they still need naps. Ethan was zonked at the start of his second match, but luckily my friend Katy came by to check out the robots, so I let her drive Scary. This would be Katy's first time driving a robot ... ever, so I knew she would represent Ethan's driving very well. In fact, she did a fantastic job in her first time out.

The low wedge of Scary did well to get under Piranha. Piranha got in a couple of hits on the wheels and back armor, while Katy got the hang of driving. A few times Piranha was up on the wedge, but she just couldn't get him into the pit.

After about a minute and half, Katy got the hang of driving and was able to get him in the pit. Scary: 1-1.

## Fight 5: Scary vs. Caribou

Ethan was still asleep, so Cayden took over the driving duties for Ethan. He did a good job, and fought for the entire three minutes. This was another good back and forth battle. Scary has a very low wedge that was able to get under Caribou. Caribou was incredibly fast and well driven, and was able to push Scary around the arena when he got him from the side or the back. Cayden was able to avoid the pit and hang on for the win. Scary: 2-1.

## Fight 6: Angry Bot vs. One Night

One Night and Angry Bot engaged in another close battle. Cayden wasn't able to get One Night into the wedge as much as he was with Cheese Wedge, but he also didn't get stuck on his back. One Night did a good job of driving Angry Bot around the arena, and staying away from the grabbing arm. One Night ultimately won in a close audience decision. Angry Bot: 2-1.

## Fight 7: Angry Bot vs. HooDoo

HooDoo was driven by an audience driver. The bot was a four-wheel drive wedge that was big enough that he didn't fit in the dustpan very well. They pushed each other around pretty consistently with both drivers struggling to make contact. Both robots were pretty quick, with HooDoo being the faster of the two, so neither driver was really controlling the fight. Cayden lost focus for just a second and drove straight into the pit. It was an unfortunate way to end his day. Angry Bot finished 2-2.

## Fight 8: Scary vs. HooDoo Wedge

Ethan was still out (he must having been getting some rest for daddy, too). Cayden stepped in to get his revenge against HooDoo. Cayden used to own a variation of Scary — which he called Speedy — so those two united and it was good. This time, the match with HooDoo ended much differently as Cayden was able to get HooDoo up onto the wedge and drive him in the pit. It was one of the better pieces of actual intentional driving that he had all weekend and it put his brother into the finals. Scary: 3-1.

Ethan was supposed to have another fight with One Night, but One Night was in rough shape after its previous fight with Calamity, so Scary got the bye into the finals.

## Fight 9: The Finals: Scary vs. Calamity

Calamity is a very tough little drum bot driven by Sam McAmis. Sam is a top-shelf driver. He finished either first or second in every class at this event, so I knew this would be a tough fight. Ethan woke up about five minutes before this fight started, so he grabbed some grapes and the controls, and went in to fight in the finals (What a baller!).

The fight started out pretty good. Ethan was using his now patented random stick mashing controls which got under Calamity a few times, but Calamity got a couple good shots on him. About a minute into the fight, Calamity went under Scary and I saw wires and the power switch come out, and more wires wrapped around the drum of Calamity.

I immediately tapped out and went in to make certain we didn't start a battery fire. Luckily, it pulled the plugs apart at the battery and broke the switch. There was no really significant damage, but the match was over. Scary: 3-2.

## Fight 10: The Rumble

In the rumble, Cayden put Angry Bot in; unfortunately, Scary was a little too beat up after his fight with Calamity (kind of a reoccurring trend with bots that fought Calamity that weekend). There ended up being eight robots in the arena for this rumble, so it was total anarchy.

Bots piled up around the pit, but everyone stayed out until over four minutes into the rumble. Unlike most other events, this one went with the "fight til Li-Pos ignite" approach. The fights raged on.

Angry Bot got a half dozen clamps and nearly pushed in a whole pile of bots, but at nearly nine minutes Caribou tipped Angry Bot



**Photo 5: The Champions collect their trophy from Event Organizer John Lamp.**

onto his back and then drove him into the pit. By then, the pit was so full that Angry Bot was almost able to self-right using the carcasses and get back into the fight, but alas he wasn't. He still ended up getting third in that battle with Caribou deservedly taking the win.

The team of Cayden and Ethan (and Katy) ended up winning second place in the Antweight class. I told you the results might surprise you. They got a really cool trophy and had a great time. Their dad had the biggest smile of the weekend. Overall, the entire event was awesome and I look forward to the next one.

## Wash, Rinse, Repeat

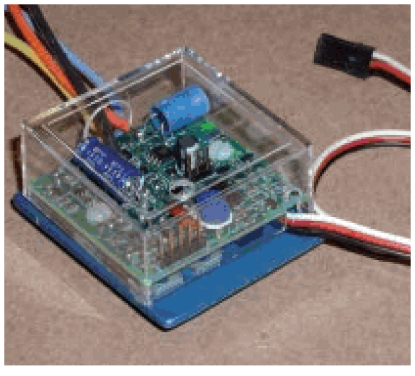
So, where do we go from here? Well, the whole way home I got to hear how they both wanted saw blades on their robots for the next event. Talk about one proud papa!

Once we got home, we started drawing pictures of robots and ultimately settled on a small wedged robot with a vertical saw blade. The design is a loose interpretation of Verbal Irony – a very successful Ant that used to fight the Florida circuit years ago.

I'll make two identical clones and then we'll start work on a fully enclosed arena so they can spar safely. In other words, we get to start the process all over again with new designs and two little builders that have been bitten by the bug.

Look for more details on these bots and our mini arena in a future issue of *SERVO*. SV


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# EVENT REPORT:
# Franklin 2013 – Fall Fun in Philly

● by Pete Smith

The Franklin Institute in Philadelphia (**www2.fi.edu**) hosted its 7th annual robotic combat event on September 21, 2013. The Institute provides the venue arena and N.E.R.C. (**www.nerc.us**) organizes the event.

I usually bring a couple of my bots to compete, but this year I decided to take a break from competing and offered to judge instead. Competing with even one bot ties up a lot of your time at an event and as I usually bring two or three, I sometimes find I miss much of the action while I'm repairing and recharging my bots in time for their next fights. I was to find judging keeps you just as busy, but at least you don't miss any fights!

There were 26 bots this year, fighting in five weight classes: 1 lb Antweight, 3 lb Beetleweight, 12 lb Hobbyweight, 30 lb Featherweight, and 30 lb Sportsman.

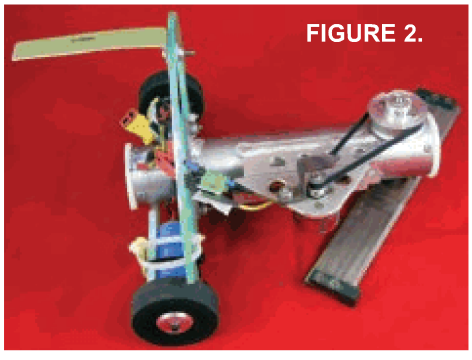
The arena is provided by the Institute, and it's a thing of beauty. It's built up of extruded aluminum sections securing the Lexan walls and roof, and has a replaceable wood floor. The bump strips were upgraded over last year, but I wasn't sure they would stand up to the fiercest 30 lber at full cry.

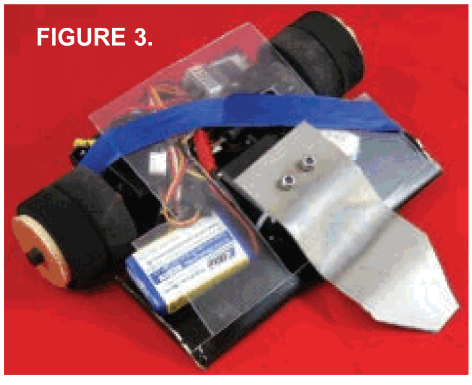
The arena and the scrolling display that I described in the February and March 2013 issues can be seen in **Figure 1**. (It's bright!) I set it up to show a link to the N.E.R.C. website and display the names of the various sponsors.

Fighting got started by about 11:30 am after the usual last minute builds in the pits and the safety tests. I was kept busy setting up my Kitbots banners and display, and setting up Team Green Machine's Beetleweight Maniac Kathy (**Figure 2**) with a new transmitter. Theirs had failed a couple days before the event.



FIGURE 1.


FIGURE 2.


FIGURE 3.

I managed to mess up the first attempt when I forgot to set the throttle at zero for binding. The bot then failed safety because the RX thought that the none-zero setting was the fail safe position. I re-binded (rebound?) the Rx with the throttle set at zero. All was well and the bot got through safety in time.

There were seven Antweights competing, but it quickly came down to four main combatants: Hanger 11, a lightly armored bot with a servo operated flipper arm (**Figure 3**); old time favorite and previous champion Poco Tambor (**Figure 4**) with its highly effective drum; newcomer Dust Pandemonium (**Figure 5**), which combined the classic dustpan shape in carbon fiber with a small high speed rotating blade; and finally, Gyroscopic with its relatively large beater bar (**Figure 6**).

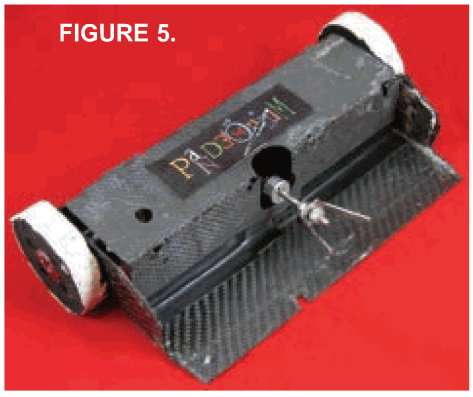
Dust Pandemonium out-drove Hanger 11 to get to the semi-finals, but then faced what looked like a quick death at the hands of Gyroscopic. However, a lucky hit with its small blade cut the o-ring belt that drove the big beater bar, and Gyroscopic tapped out soon after.

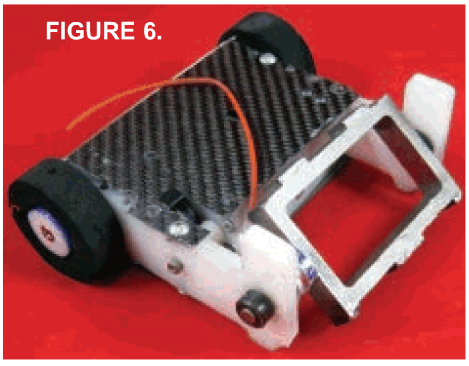
The Antweight finals were between Poco Tambor who was undefeated through the winner's brackets, and Dust Pandemonium who had come up through the loser's brackets. Poco Tambor seemed to lose drive early on, and his opponent took advantage to control the fight and win by a clear judge's decision. Since Poco Tambor had only lost once so far, they had to fight again to decide who was the champion.

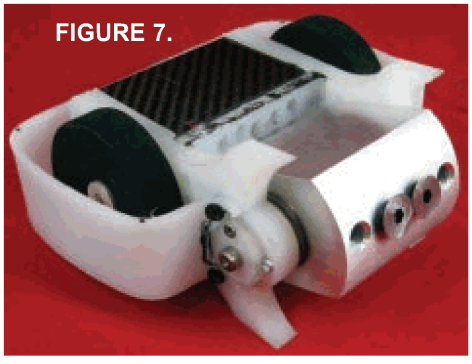
In the second final, Poco quickly knocked out the drive on one side of its opponent but an out-of-balance drum resulted in traction problems. The fight went to the judges with Poco Tambor getting the decision.

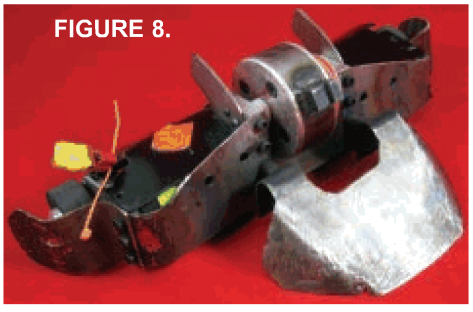
Eleven Beetleweights took part,

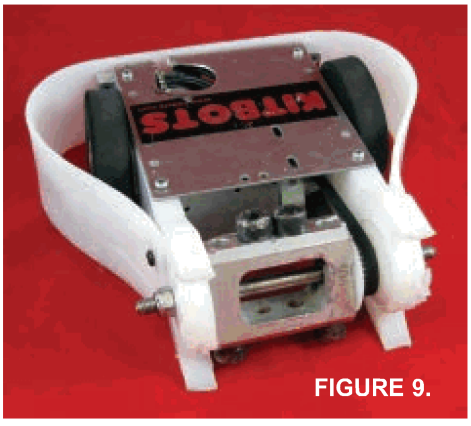


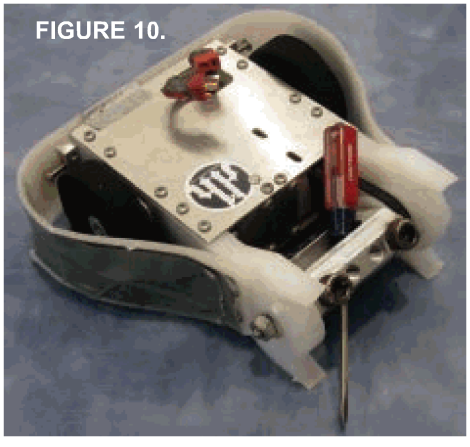



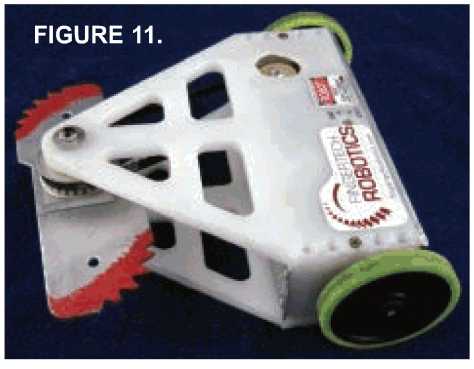



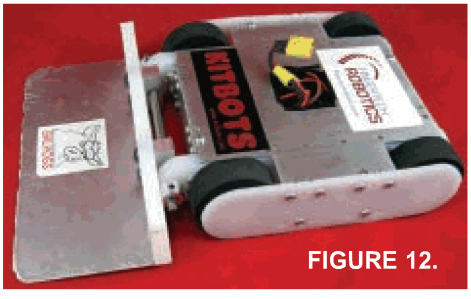




including former champion Maniac Kathy with it horizontal spinning bar; the uber drumbot Grande Tambor (**Figure 7**) which had a new and better balanced drum for the competition; Mr. Croup (**Figure 8**) with its titanium armor and very effective drum; and two Kitbots' Weta kits — Play'n Krazy (**Figure 9**) and this year's Motorama champion Mondo Bizarro (**Figure 10**).

Also taking part were the horizontal spinner Traumatizer (**Figure 11**); a modified BattleBots toy called Bazinga; Kitbots Trilobite kit Thunder Child (**Figure 12**); overhead spinner Void (**Figure 13**); and drum spinner The Rolling Pin II (**Figure 14**).

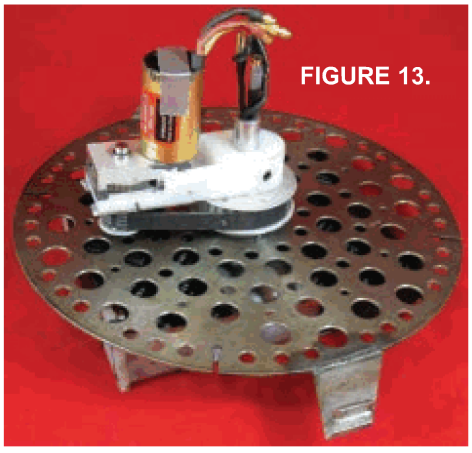
This last bot is particularly interesting as the drive is pivoted along the longitudinal axis so it can maintain contact with the ground even when the rest of the bot gyrodances when turning. This improves mobility with the drum at full speed. The weapon's friction drive is also unusual in that it uses o-rings directly on the bell of the Outrunner for powering the weapon.

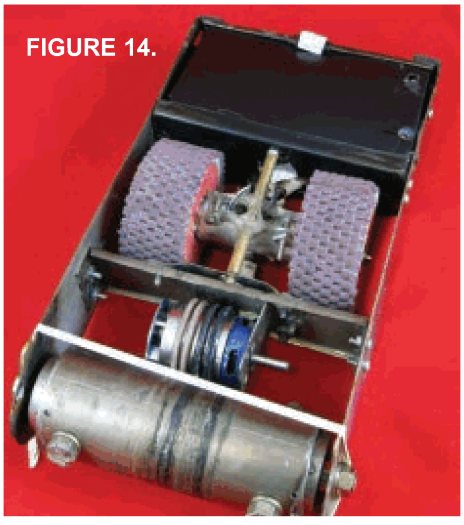
Possibly the best fight in the first round was Play'n Krazy versus Traumatizer. Early hits by Play'n disabled the drive on one side and removed the screw that secured the weapon axle on Traumatizer, which then self-destructed when its own blade hit its chassis.

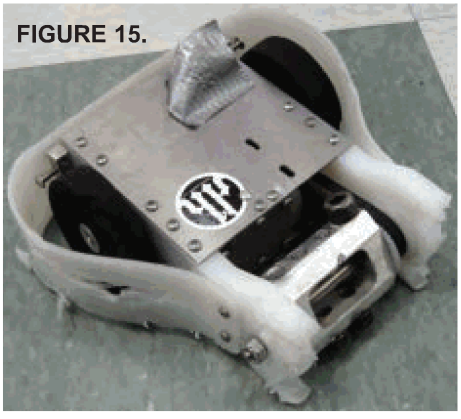
The biggest surprise in the first round was the defeat of the Motorama champion (Mondo Bizarro) — its first loss in 15 fights. It was holding its own against The Rolling Pin II — despite having lost drive on one side — when its battery decided 15 fights was enough and failed.

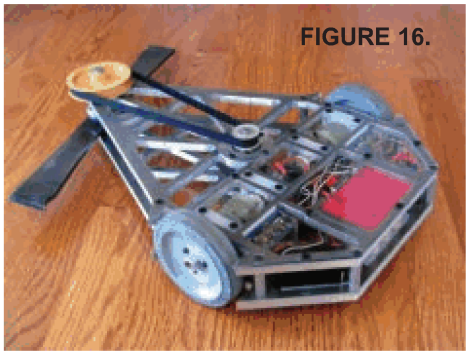
In the next round of the Beetles, the highlights were Maniac Kathy knocking out Bazinga, and Grande Tambor quickly defeating Play'n Krazy. Grande Tambor's new drum was so well balanced as to be near silent, but perhaps the hits did not seem as hard as those of the old drum.

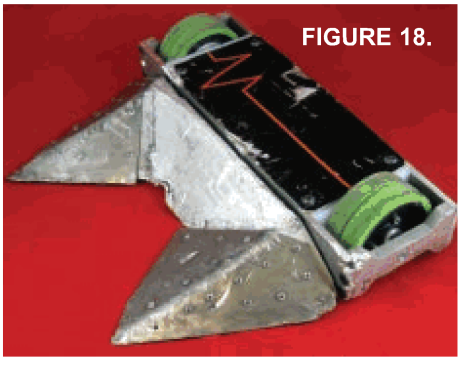
It turns out the kV of the motor fitted to the new drum is lower than what was in the previous version. It will be replaced for the next event

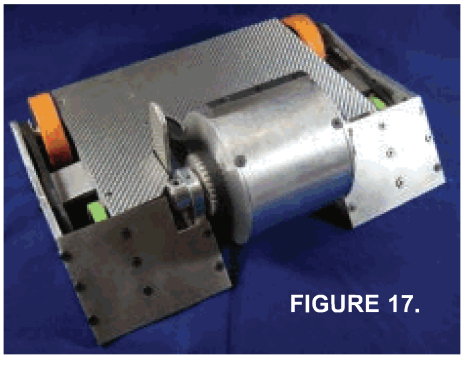

FIGURE 13.

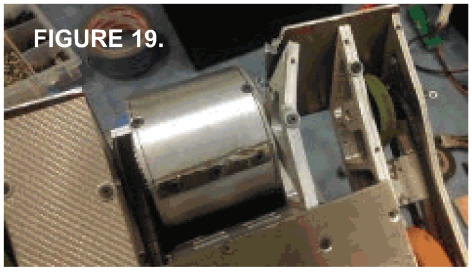

FIGURE 14.


FIGURE 15.


FIGURE 16.


FIGURE 18.


FIGURE 17.


FIGURE 19.

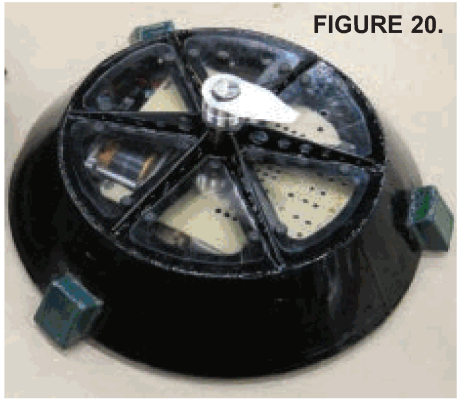

FIGURE 20.



FIGURE 21.

to get its performance back up to its fearsome "normal."

As the brackets thinned out, Maniac Kathy had a good fight against Play'n Krazy and won when the latter got stuck at the one position where he balanced with the drive wheels off the ground.

Mondo Bizarro — now running on a borrowed battery — almost suffered the same fate in its fight against Maniac Kathy, but it has a heavier and faster beater bar and so was able to throw itself back onto its wheels. It quickly went on to remove one of Maniac Kathys' wheels and win by tap out.

In the winner's bracket semi-final, Grande Tambor and Mr. Croup had a close match with Mr. Croup seeming to have the advantage when his opponent lost drive on one side, but then it swung the other way when his own weapon failed and he tapped out when a lucky hit left Mr. Croup balanced upside down and helpless.

In the loser's bracket semi-final, Mondo Bizarro just edged a judge's decision over Mr. Croup, so it was the Motorama champion versus Grande Tambor in the final. This was a classic.

Mondo Bizarro was clearly getting in the better hits and looked to be cruising to a win when with less than a minute to go, he lost one of the teeth in his beater bar and the resultant severe vibration made the bot nearly un-drivable. Grande Tambor took advantage of this to get in several big hits and Mondo Bizarro was motionless by the time the buzzer sounded for the end of the fight.

Mondo Bizarro with its missing tooth can be seen in **Figure 15**.

There were three Hobbyweights competing this year: Fiasco with its big horizontal blade (**Figure 16**); the drum spinner Upchuck (**Figure 17**); and the fast wedge Flatline (**Figure 18**). Fiasco had already fought and dismantled Upchuck at Motorama this

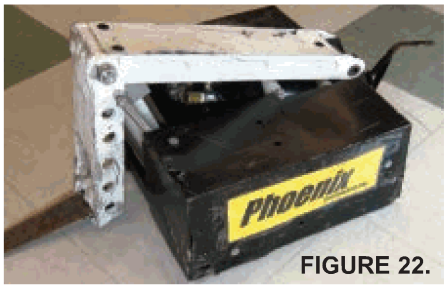
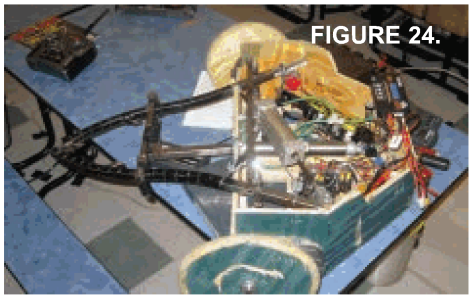
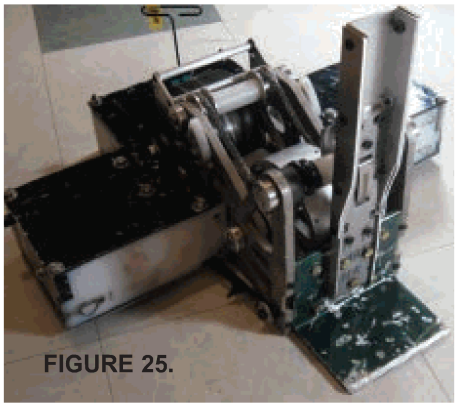
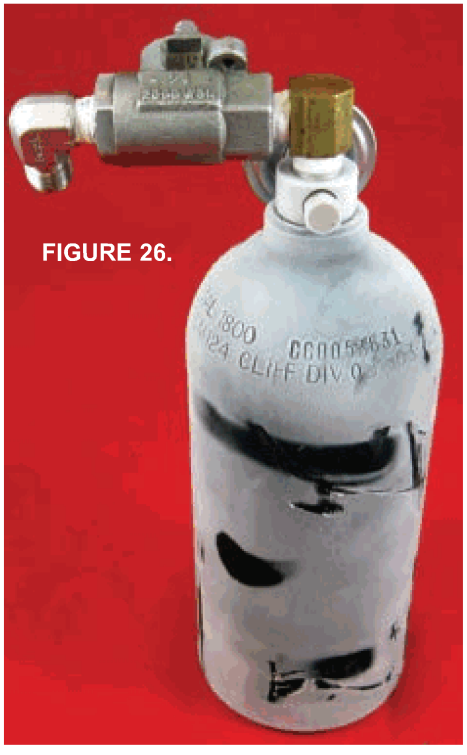


FIGURE 22.


FIGURE 23.


FIGURE 24.


FIGURE 25.


FIGURE 26.

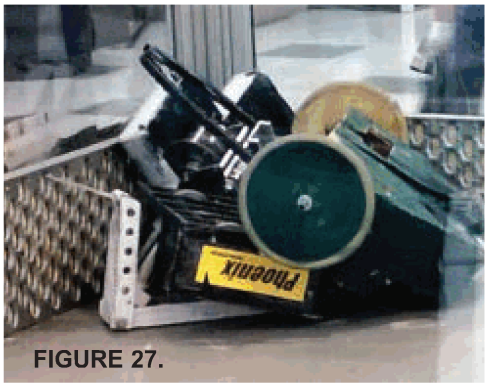


FIGURE 27.

year, and Upchuck had little more luck at Franklin. This time, it took two hits, and the damage was not quite so bad (**Figure 19**) but the result was the same – a quick win for Fiasco.

Upchuck had won handily against Flatline in their first fight but without its weapon working properly. Possibly due to undiscovered damage, it was dominated by Flatline in the loser's semi-final, so the wedge advanced to the finals.

In the finals, Flatline won the first round after Fiasco's weapon drive failed, but with double elimination a bot has to lose twice.

In the second fight, a good hit by Fiasco distorted the rear panel of Flatline enough that it lifted both drive wheels off the ground to reduce the wedgebot to near immobility. Fiasco won on a judge's decision.

There were only two 30 lbers, so there was only one fight. It was the very destructive full body spinner Tetanus (**Figure 20**) against the "built at the last minute" wedge Re-Enforcer (**Figure 21**).

| | | |
|---|---|---|
| **Antweights** | 1st | Poco Tambor |
| | 2nd | Dust |
| | | Pandemonium |
| | 3rd | Gyroscopic |
| **Beetleweights** | 1st | Grande Tambor |
| | 2nd | Mondo Bizarro |
| | 3rd | Mr. Croup |
| **Hobbyweights** | 1st | Fiasco |
| | 2nd | Flatline |
| | 3rd | Upchuck |
| **Featherweights** | 1st | Tetanus |
| | 2nd | Re-Enforcer |
| **Sportsman** | 1st | Jack Reacher |
| | 2nd | Upheaval |
| | 3rd | Phoenix |

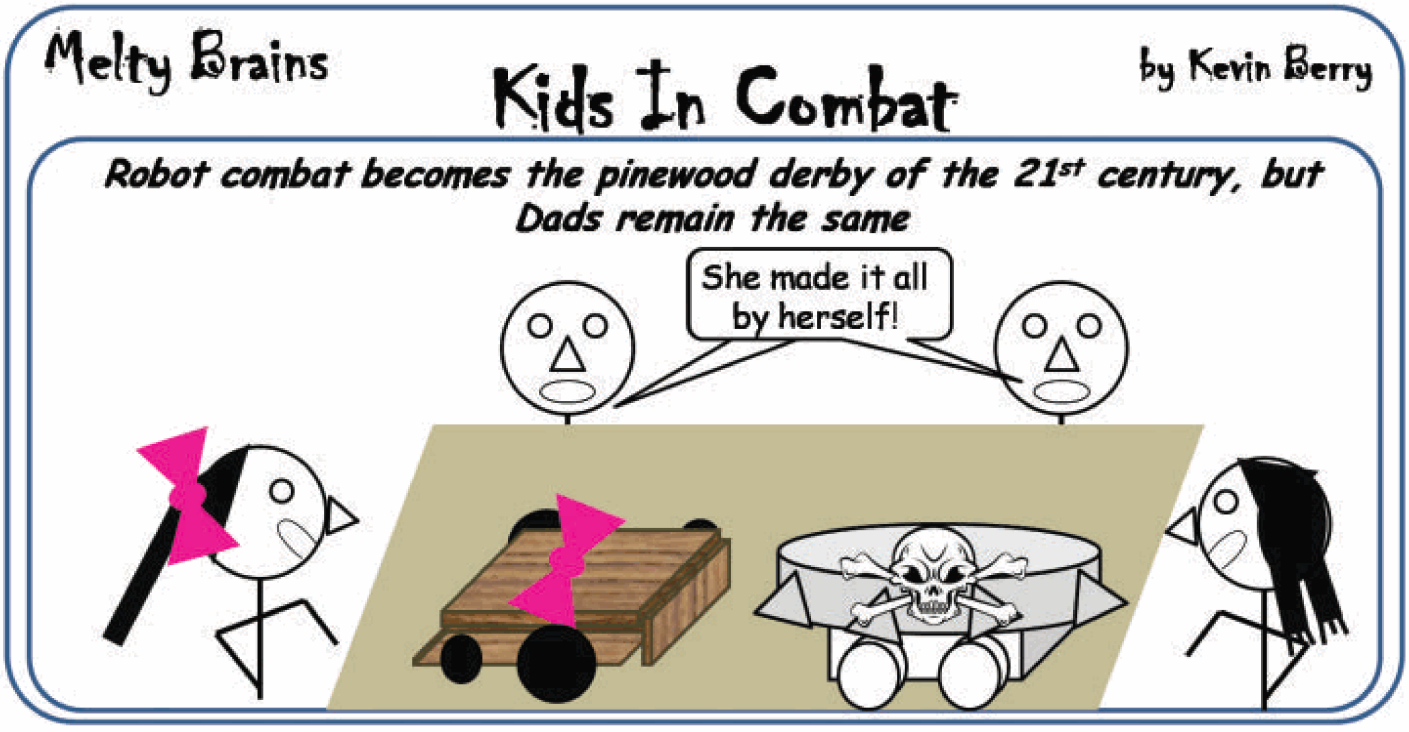
It turns out that the latest Harbor Freight drill motors – while fine in a 12 lb Hobbyweight or in a 15 lb BotHockey bot – simply are not suitable in a 30 lber.

Re-Enforcer had a 1/2" thick steel wedge but with the drive already not working properly, it was unable to keep it facing its opponent and one good hit from the spinner immobilized the wedgebot and a second ripped off a wheel. Re-Enforcer tapped out.

The last class to compete at Franklin was the 30 lb Sportsman. There were five bots competing, and since damage is unusual in this class they fought round-robin.

There was a hammer bot, M.See.Hammer; two pneumatic flippers, Phoenix (**Figure 22**) and Upheaval (**Figure 23**); a bot with two clamping arms, Creebot (**Figure 24**); and the uber cool kinetic flipper, Jack Reacher (**Figure 25**).

M.See.Hammer burned out something after one win and retired; Creebot grabbed its opponents well, but its "Barbie




Powerwheels" drive lacked the power to do much once having done so.

The real stars of the class were the three flippers. Phoenix showed that the $CO_2$ powered flippers could be "cool" too, as can be seen by its frost covered storage cylinder after a match (**Figure 26**). Upheaval won the battle against Phoenix when the latter ran out of gas to flip itself back onto its wheels. The match between Jack Reacher and Upheaval was a classic example of good sportsmanship.

Upheaval righted Jack Reacher when he could have left him alone and got the win. Jack Reacher went on to win a close judge's decision to win the class overall.

It seems that if the self-righting issues can be resolved, the kinetic flippers may have the advantage of having a greater number of operations than is possible for the pneumatic powered bot due to the limited gas storage allowed in the class.

Upheaval got its revenge a little later by swiftly piling up all the other bots in a corner to win the Sportsman class rumble (**Figure 27**).

The event finished in the early evening with everyone having had a good time and looking forward to the next big N.E.R.C event — Motorama in February.

I enjoyed judging and have a little more appreciation as to just how hard it is to decide who is the winner in some of the fights. I'll hopefully be coming to Motorama and if I do, it will probably be to compete but I can see myself returning again just to judge. It's much less stressful than competing and you get a front row seat! **SV**

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# THEN AND NOW:
## A Decade Later With Alexander Rose

● by Kevin M. Berry

*This is the next installment in our series of articles about famous figures from a decade ago. 2002 ended the popular Comedy Central series, BattleBots™. 2003 inaugurated a new era in combat robotics, where our sport left the spotlight and we tried to fly on our own. Grassroots events sprung up everywhere, as documented in our 2012 series of articles, "The History of Robot Combat." Almost a dozen years later, the sport continues to attract new builders, and events keep chugging along.*




Combat Zone caught up with Alexander Rose, co-builder of the famed Super Heavyweight Toro — one of the most impressive machines in our business. Rose and his Inertia Labs partner Reason Bradley were dominant in the sport for many years. Toro, driven by Reason, was also the other bot in the famous "flip it again!" clip from BattleBots 4.0 — chronicled in our interview with Dick Stuplich, builder of New Cruelty.

As part of the team fielded by Inertia Labs, Toro fought in BattleBots 2.0 through 5.0, as well as the first BattleBeach event. Inertia Labs also built: T-Minus, a middleweight version of Toro; Matador, the Heavyweight complement; and a collection of Antweights. (Rose's Antweight pneumatic flipper Pele defeated my rather lame loaf pan bot at BattleBeach 1. He was a gracious winner, and I somehow managed to conceal my pleasure at getting beaten by Toro's co-owner. I did, to the bafflement of my young son, yell "flip it again!")

**Combat Zone:** Alexander, how did you get started in the sport?

**Rose:** Reason Bradley and I both grew up in a junk yard in Sausalito that was where they built Liberty Ships in WWII. He became a machinist and I became a designer, and when I came back from college he mentioned this competition to me called (then) Robot Wars going on in San Francisco, CA. It was two weeks away, and we just started building every night at the shop he worked at. We barely made a robot that could compete at all that year, but we learned a lot and came back the following year with something more competitive. It wasn't until BattleBots started up that we had a real contender.

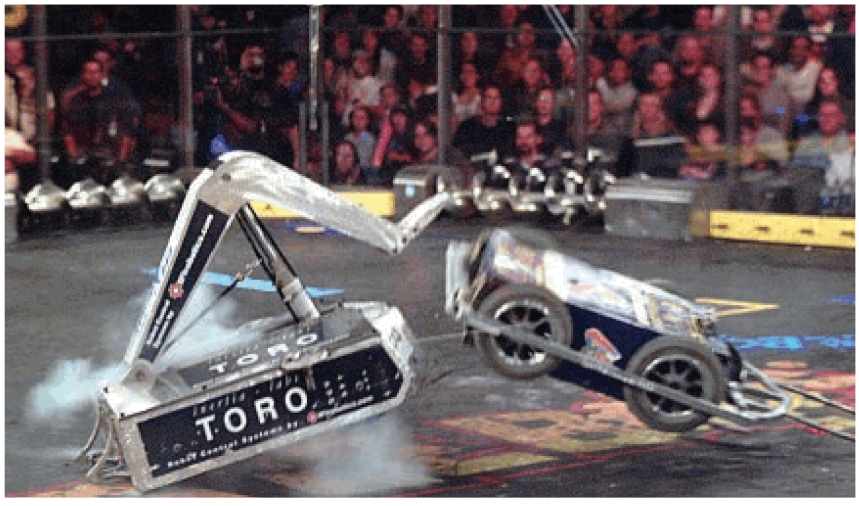
**Combat Zone:** What were the early TV days like? Any special memories?

**Rose:** My most vivid memory of the early days was, I think, the second BattleBots show which was filmed in Vegas. It was the first year we brought Toro, and it was the first

Super Heavyweight flipping robot and I think the first to really violently flip the opponent. Few to none of the Super Heavies had a way to self-right or work upside down.

We lost, however, in an early round because of a loose radio battery, but came back in the melee to flip all the other robots in quick succession for the win.

This was our first real victory, with the entire crowd going nuts chanting "TORO, TORO." I will certainly never forget that. (*Editor: The loss was to Atomic Wedgie.*)




**Combat Zone:** How would you describe the participants during those mega TV sessions, versus the atmosphere we are all used to at the more builder-run events?

**Rose:** BattleBots was builder-run from the get-go. Trey (Roski) and Greg (Munson) were very builder-centric and tried as best they could to keep a level playing field that anyone could join. However, when we hit 500 entries or so, this made the early elimination rounds really brutal. These were not filmed for TV. In order to get to the TV rounds, you had to fight a lot of fights against unknown bots. This changed the competition to being a lot more about how fast you could repair your robot and get it back into fighting shape than any of the events before.

Towards the end when we were running four bots, we made our whole shop portable and put it in wheeled cabinets. This way, we could run our own pits out of a large rental truck in the parking lot where we had everything close at hand including things like TIG welding.

**Combat Zone:** Most memorable win? Biggest loss?

**Rose:** Our most memorable win for me was T-Minus vs. Hazard which was not only the middleweight champ, but it had never even lost a bout. Hazard's helicopter-like rotary blade weapon had absolutely destroyed every robot it came across.

We had to go against Hazard in the quarters or semis of the last season of BattleBots and we were pretty nervous. T-Minus had a powerful flipping arm, but we did not want Hazard to get close enough to hit us while we tried to flip it over. So, we went over to see it in the pits and while I chatted with Tony (Buchignani), Reason got a measurement of exactly how much reach his blade weapon had.

We then welded a small titanium tab onto our flipping arm that would stop Hazard from getting too close by jamming up against its bodywork. This turned out to work perfectly and as Hazard drove right into us, the weapon was just out of reach. We then flipped his own bodywork up into his weapon, causing catastrophic failure. We went on to get the middleweight championship title.

My most memorable loss was certainly the first year we brought our Heavyweight robot Matador. It had the most powerful flipping arm we had ever built, at 21,000 pounds of force. We were really confident in it and had a good amount of testing time on it. Unfortunately, however, it had exposed wheels and when we went up against a spinning weapon robot it had each of its wheels mowed off one by one for a pretty humiliating loss. (*Editor: This was against M.O.E. at BattleBots 4.0.*)

**Combat Zone:** Any advice for newbies wanting to get into the sport?

**Rose:** My advice for any sport — especially one that is technology driven — is to go in with a long term plan. Make the first entry just about getting there and competing. Just going to your first event, you will learn a lot about the whole sport. Then, aim to make the second entry at least competitive. By your third, you should be aiming to win. The last bit of advice is to get done early enough for lots of driving practice. Way too many bouts are lost due to poor driving because the event was one of the first times they drove it.

**Combat Zone:** What have you been up to since the end of the televised fighting era? Anything you'd like our readers to know about?

**Rose:** I've been working on building a monument scale 10,000 year clock with The Long Now Foundation (**http://longnow.org**/) and Reason has started a new company called Universal Sonar Mount which makes a patented sonar mount for survey vessels (**http://universalsonarmount.com**/). We still make some small robot kits that are sold through Robot Marketplace, as well as periodically do fun robotics projects like BarBot.

Our latest creation there was a robot that makes Manhattans, and another giant Tiki robot that makes Mai Tais. **SV**

# Build the Plastic Bot of Destruction

## Part 3



By Michael Simpson

Post comments on this article and find any associated files and/or downloads at **www.servomagazine.com/index.php/magazine/article/january2014_Simpson.**

**A lot of things have changed this month. I finally got a new tube for my laser and was able to run through a couple new prototypes of the PBOD. This has resulted in some major design changes. The new design uses parts that can be made in three ways:**

- **3D printed parts**
- **Laser cut parts**
- **CNC machined parts**

**I will point out the differences as I take you through the assembly of the new machine.**

## Wheels

The first change in the design is the wheels. While you can make the tires shown in last month's article, the new components shown in **Figure 1** will add some construction options.

### Wheel Assembly

The new construction is a little different than what was shown last month. You assemble the main hub using four #4-40 x 3/4" machine screws and lock nuts as shown in **Figures 2A** and **2B**. The 3D printed hub is a single part, but still needs the screws. The screws are also used to hold an inner support hub which will be installed later. When assembling the laser cut gears, you need to make sure the teeth are aligned.

**Figure 3** shows the laser cut tires. They can be stacked in many configurations. You can use a single tire or up to three on each wheel.



Figure 1.



Figure 2A.



Figure 2B.



Figure 3.



Figure 4A.

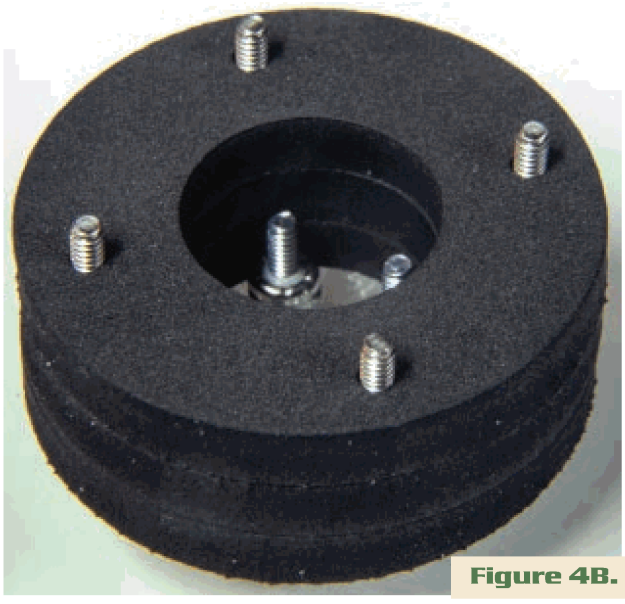


Figure 4B.



Figure 5A.



Figure 5B.



Figure 6.

To add three tires to the hub, insert four #4-40 x 1" machine screws through the hub and then through the stack of tires (refer to **Figures 4A** and **4B**).

To secure the tires, you need to tap the four holes in the hub cap with a #4-40 tap. Then, tighten the four machine screws so they protrude about 1/4" as shown in **Figure 5A**. Optionally, you can add four #4-40 lock nuts as shown in **Figure 5B**.

The last step in the wheel assembly is to drop the inner support hub into the center of the wheel so that the four holes slip over the screws; take a look at **Figure 6**. Note that this hub will be held in place with the main mounting nut later.

This concludes the wheel construction. I will post the STL files for the hub parts on the PBOD website. For those without a 3D printer that want to build the PBOD, I will offer wheel and tire sets, as well.

## Chassis Assembly

While the design for the chassis has changed, it still goes together as shown in the last article. A couple things led me down the road for this particular design.

### Motor Controller

Originally, I was using a Dimension Engineering Sabertooth 2 x 12 RC motor controller. While you can still use this controller (as I kept the hole pattern in the chassis bottom), I added a second set of holes that will allow you to mount the smaller Sabertooth 2 x 5 RC motor controller shown in **Figure 7**. This motor controller can easily control all the motors in the PBOD. Its smaller size yields more space inside the chassis for a battery or other payload.

You can get more information on both the 2x12 and 2x5 controllers at **www.dimensionengineering.com**.

### Motors

I was able to test a couple different motors available from SparkFun (**Figure 8**). Of the motors I tested, the ROB-12007 and ROB-12008 work the best in the PBOD. The ROB-12007 will make your PBOD faster, but it will have less torque. This is good for smooth surfaces with a lot of room. The ROB-12008 is slower, but yields more torque. It works well on surfaces with more traction like rugs and carpets. It is also easier to control and capable of precision movements. I have used both two and three cell Li-PO batteries with success. The size of these motors allowed me to place both of them at the rear of the PBOD. This adds a much larger payload area inside, plus makes access to the motor controller easier for motor hookup. You can get more information on the motors at **www.sparkfun.com/products/12008**.

### Step 1

Start by installing the two end chassis parts to the bottom chassis part as shown in **Figure 9**. Use four nylon #6-32 x 3/8" machine screws and four hex nuts to secure them.

### Step 2

Install the two sides using five #6-32 x 3/8" nylon machine screws and hex nuts on each side as shown in **Figure 10**. Notice the orientation of the motor cutouts. They are located at the rear of the bot. The rear bottom part is the end with the controller cutout. The end with the small slot is the front of the bot.

### Step 3

Place a washer on six #6-32 x 1-1/2" machines screws and insert them into the six lower holes (three on each side) from the inside; refer to **Figure 11**. Add lock washers and #6-32 hex nuts, then tighten. Don't over-tighten or you stand a chance of damaging the plastic.

### Step 4

Place a washer on a #6-32 x 1" machine screw and insert it into the top hole opposite the motor cutout (**Figure 12**). Add a lock washer and hex nut. Tighten the nut. These are the two idler gear axles.

### Step 5

Place a #2 washer on two #2-56 x 1/2" machine screws and insert them into the two holes as in **Figure 13**. Add a second washer to each screw and secure with a #2-56 nut. Finger tighten only.

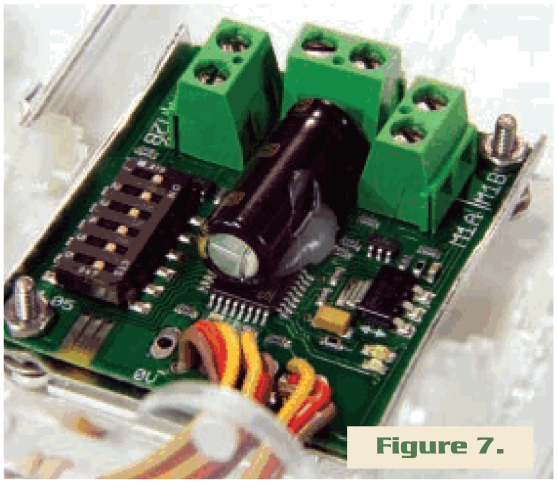


Figure 7.

Figure 8.



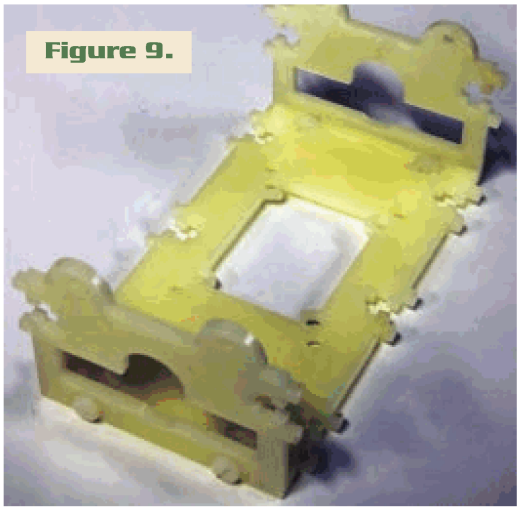


Figure 9.

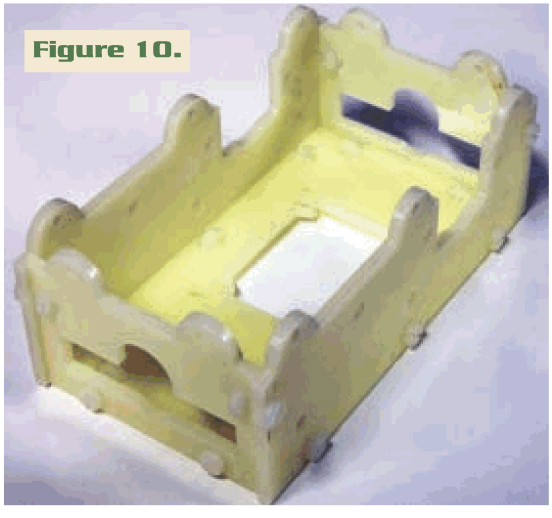


Figure 10.

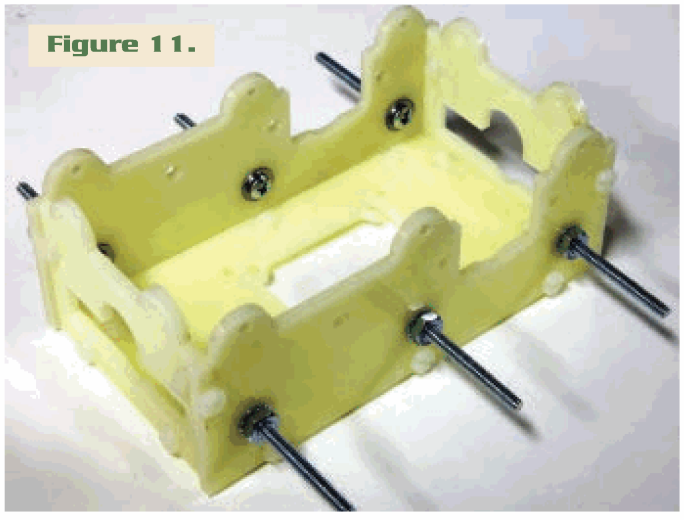


Figure 11.

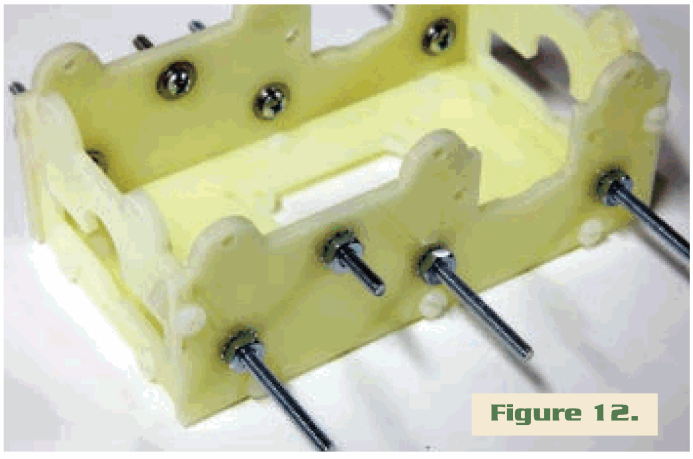


Figure 12.

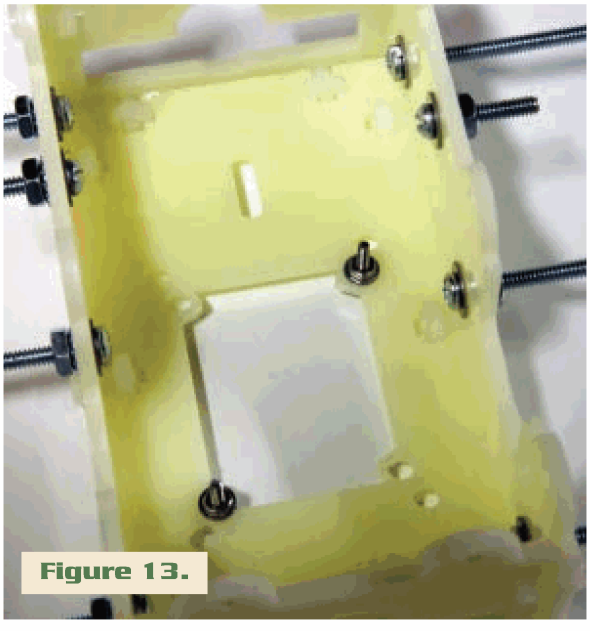


Figure 13.

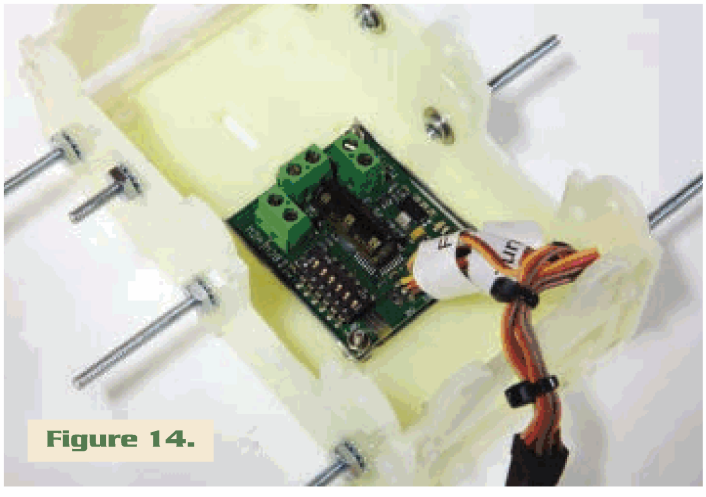


Figure 14.

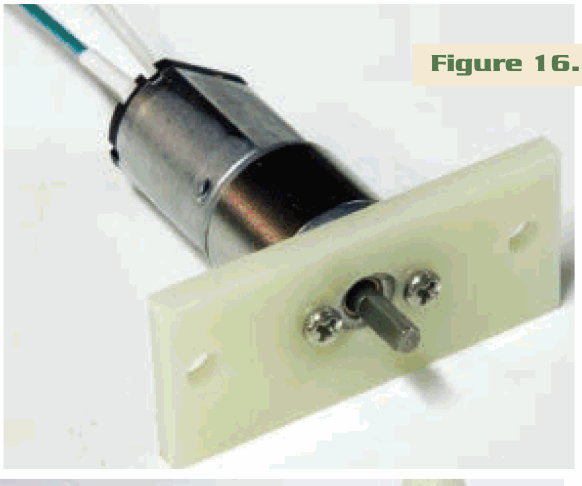


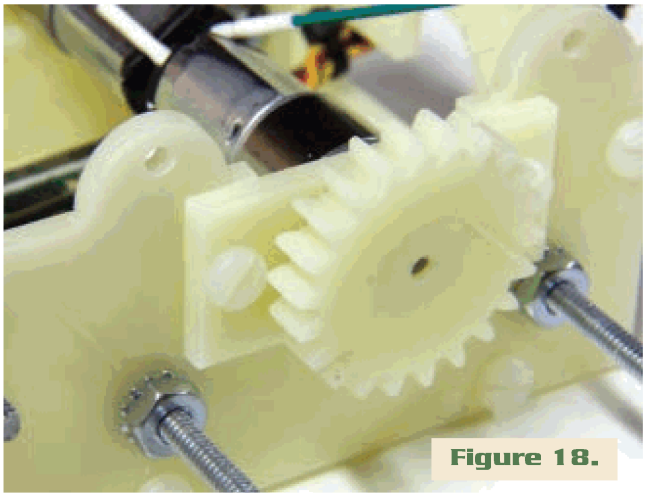
Figure 16.

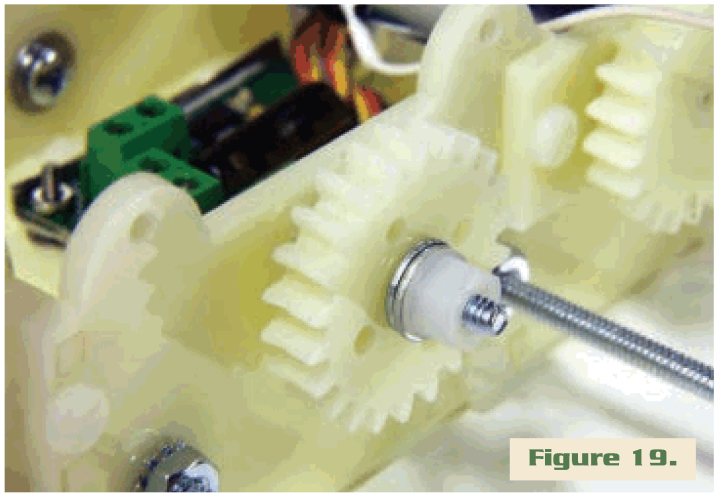


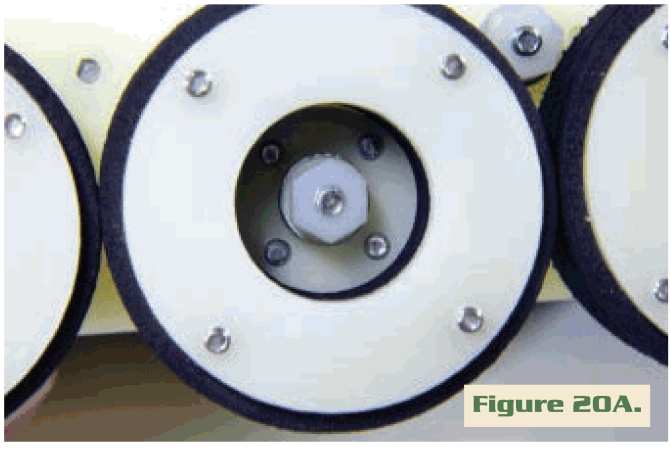
Figure 15.

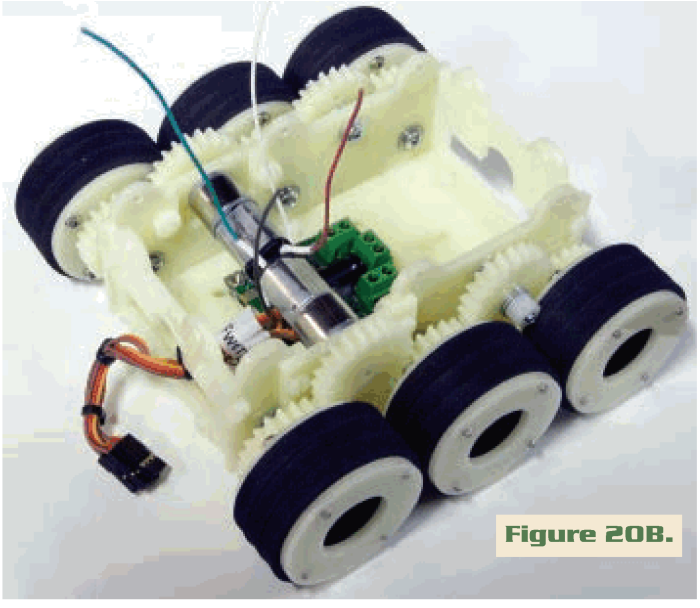


Figure 17.


Figure 18.


Figure 19.


Figure 20A.


Figure 20B.

### Step 6

Slip the motor controller over the screws as shown in **Figure 14**. If the controller won't fit over the screws, loosen them a little. Once in place, tighten the screws from the underside of the chassis. Add a #2-56 nut to each of the screws and tighten. Pay particular attention to the orientation of the board.

### Step 7

Cut four pieces of 18-20 gauge wires to 3" in length. Solder them to the motors and add some heat shrink as you can see in **Figure 15**. Strip about 1/4" of the insulation from the other end of each wire.

### Step 8

Referring to **Figure 16**, attach each of the motors to motor mounts. Use two M2 x 3.5 mm machine screws to secure the motor.

### Step 9

Slip the two press-fit gears over the motor shaft as shown in **Figure 17**. The outer gear should be flush with the shaft.

### Step 10

Use two nylon #6-32 x 3/8" machine screws and hex nuts to attach the motor mounts to the chassis as in **Figure 18**.

### Step 11

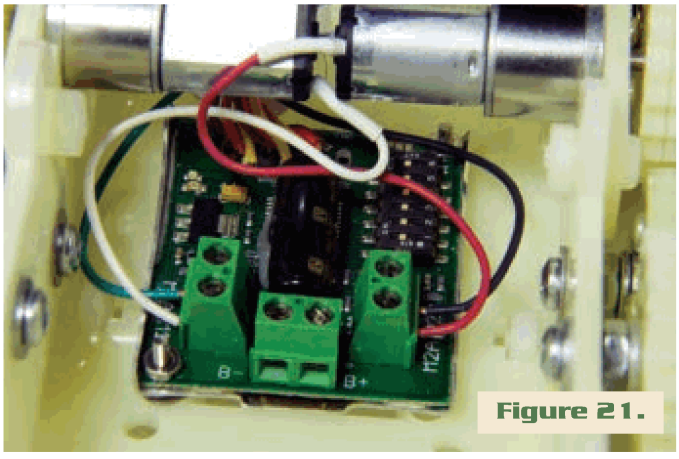
Insert two washers over the idler axle. Next, slip two of the idler gears over the axle. Then, add two more washers and secure with a #6-32 nylon lock nut as shown in **Figure 19**. The nut should be loose enough to allow the gears to turn freely. Do this on both sides of the chassis.

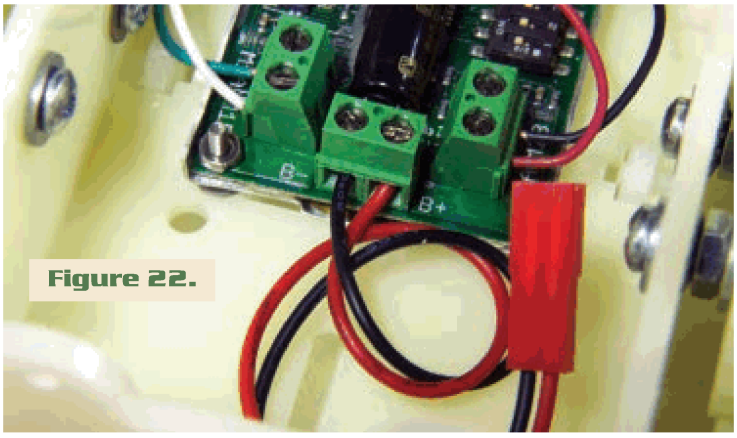
### Step 12

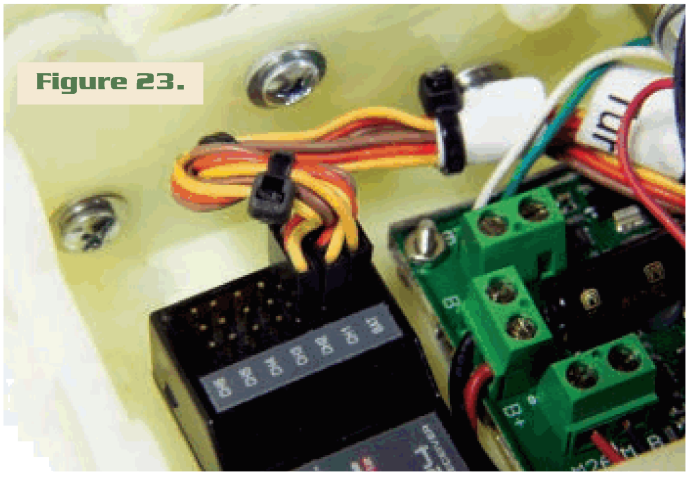
Insert two #6 washers over each of the six wheel axles. Insert an assembled wheel over each axle. Be sure the inner support hub is in place, then add two more washers and secure with a nylon #6-32 lock nut (refer to **Figures 20A** and **20b**). The nut should be loose enough to allow the wheel to turn without binding.

### Step 13

Attach the motor wires to the terminals that are located on its same side as shown in **Figure 21**. Don't


Figure 21.


Figure 22.


Figure 23.

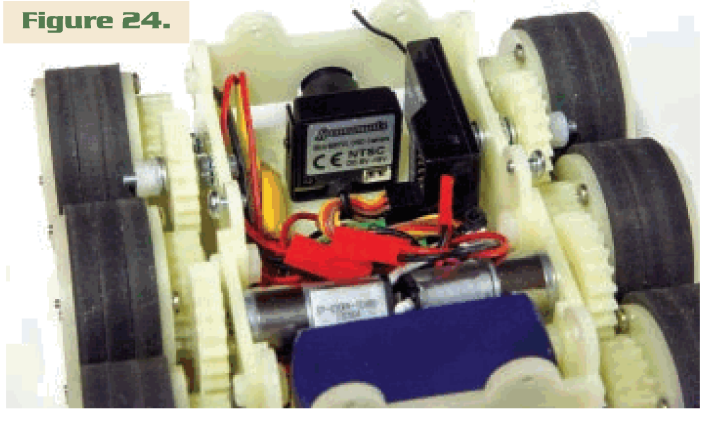
worry about the wire colors at this time, as you will be testing the PBOD later.

### Step 14

Insert the battery connector as shown in **Figure 22**.

### Step 15

Attach the controller cable labeled CH1 to channel 1 on your receiver. Attach the controller cable labeled CH2 to channel 2 on the radio. Connect the controller cable labeled "Flip" to the terminals on the radio labeled "Bat." The yellow wires should face the center of the radio as you can see in **Figure 23**.


Figure 24.

## Testing the PBOD

At this point, you can test your motor hookup.

Power up your bot by attaching a battery to the battery connector. If you have not done so yet, bind your transmitter to your radio. With the bot and radio powered up, move the elevator control forward slightly and make a note of the direction the wheels want to turn. Depending on what the bot does, you will need to perform one of the following actions:

- Both sets of wheels move forward: Radio is set up.
- If one side moves forward and one side moves backwards: Reverse the wires on the side that moves backwards.
- If both sets move backwards: Reverse the elevator axis on the radio.

Once the bot is moving forward and backwards according to the way you move the elevator control, you can move on to the turn control test.

Move the aileron control left and right. If the bot does not follow the control, you will have to reverse it.

That's it! Take your bot for a spin.

## Conclusion

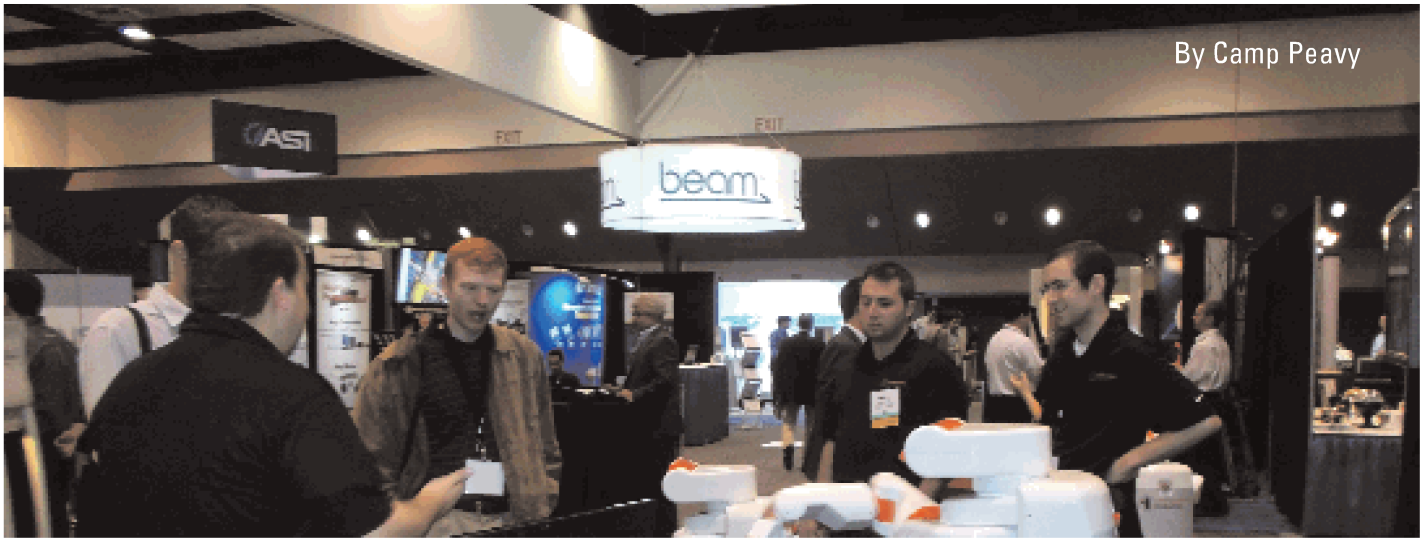
You might be asking, what are we going to do with all that payload space? **Figure 24** shows a small camera that I attached to the bot. This camera connects to a transmitter that sends video back to it which lets me drive the bot all around the shop and lab without having to leave my chair.

You can find the STL files for the various parts on the PBOD web page at **www.kronosrobotics.com/pbod**.

In addition, I will place some tire, wheel, and chassis parts up on my website for those of you who don't own a 3D printer. Next month, we will be looking into a top platform that will hold our spinner weapon system.

Please be sure to post questions and suggestions in the *SERVO Magazine* forums at **http://forum.servomagazine.com/viewtopic.php?f=49&t=17029** or at the article link. SV

# RoboBusiness 2013




By Camp Peavy

# A View from the Expo

Robotics is going corporate. I spoke at one of the original RoboNexus events some years ago ... an event designed to blend hobby and business robotics. Unfortunately, there is still a wide gap.

For example, Rethink Robotics Baxter and Unbounded Robotics' new UBR-1 were probably the highlights of RoboBusiness 2013. With heavy hardware like this to sell ... let's just say they aren't pitching to the "maker" crowd. Baxter (at $22,000) is a new low cost two-armed robot. Most traditional one-armed industrial robots cost over $100,000 and for safety need to be enclosed in a cage. Baxter, on the other hand, is "compliant" — meaning that it can work among people. Plus, it's easier to train.

UBR-1 (pronounced "uber one") is basically a replacement for Willow Garage's famous PR2 — a two-armed research robot which cost over $200,000 and introduced the world to ROS (Robot Operating System). UBR-1 continues the ROS revolution at only $35,000 with only one arm, however.

Cruising through the aisles, one would occasionally encounter a "Beam" — the new telepresence robot from Suitable Technology which could be rented for $50 an hour — good way to attend the expo on a budget! In talking with the 'telepresent' lady who was physically in Los Angeles, CA, it was almost like she was standing next to me. She said the experience was the same for her. It was literally almost like being there.

At $16,000 each, the Beam isn't a hobby class robot, but if you consider the cost and hassle of business travel and how one could be at a conference hundreds of miles away virtually, saving time, money, and energy, it wouldn't take long before the $16,000 was recouped and the savings added to the bottom line. (This business robot thing might just work after all.)

Other high-end toys included the $75,000 Velodyne LiDAR (Laser Radar). This is the sensor that makes the self-driving Google car possible. Velodyne also offers a less expensive LiDAR with only 32 lasers instead of the 64, so again things are moving in the right direction: less expensive.

I'm always on the lookout for mobile robots. We've had robots in factories for decades now but when we talk about robots of the 21st century we're referring to mobile robots. Two demos which caught my eye were the Adept Lynx and Budgee. Now this was an interesting juxtaposition!

The Lynx is a serious industrial robot which had been programmed to roam up and down the expo halls autonomously looking for the end of the conveyer belt (apparently, it had the conveyer belt attached). While the price of Lynx isn't published, from what I've read it's somewhere between $30,000 and $100,000, depending on the configuration. Serious industrial applications include clean rooms, labs, hospitals, warehouses, and plants.

A robot that can get from one place to another autonomously would be a very valuable asset in a variety of businesses. Slowly, but surely, the mobile robot revolution is happening.

Budgee, on the other hand, seems to be reaching towards the consumer market being relatively inexpensive at $1,400. According to the company, Budgee is "the friendly robot who carries your stuff." That's a cool idea. When you think about it, the basic functions of a mobile robot are to fetch and carry, so a simple device that just follows you around carrying your stuff would be useful in a variety of scenarios (although Budgee has none of the navigation capabilities of the Lynx).

Another popular kiosk was the Yaskawa Motoman Yogurt Factory. This is basically a vending machine where you insert a credit card and the robot makes a yogurt for you (at RoboBusiness 2013, the yogurts were free!). You select the flavor, toppings, and souvenir cup.

Carnegie Mellon Silicon Valley demoed their Romibo project which features a pet-like social robot designed for therapy and research, and promoted their current emphasis on personal assistive robots.

There were some goodies for the hobbyists like ROBOTIS and VEX in attendance. It looks like ROBOTIS is moving into full-size humanoids with their THOR-MANG (Tactical Hazardous Operations Robot) humanoid and its Dynamixel servos. VEX is focused on the educational market using robotics to teach STEM (Science, Technology, Engineering, and Mathematics).

I work for Neato Robotics as a technician and they were there, too. Our robots are consumer products starting at $400. The Neato XV series also happens to be an excellent hacking platform with the API available through USB and a built-in LiDAR. The primary function is, of course, vacuuming. Our booth featured a navigation pen and a radar-map demo.

What stood out for *not* being at the show were 3D printers. At Maker Faire, for example, it seemed every other booth had a 3D printer. Personally, I feel this is a space where the hobbyists are ahead of the business world. In fact, I'm of the opinion that the telepresence revolution will happen at home first. In business, no one wants to seem "silly" so they resist the idea of virtual telepresence. With the price of wireless web cameras so cheap, however, how much could it cost to put wheels on them?

For home use, I could see someone trying out one of these products to check in on the kids or elderly parents, for security, and to play with the cat. Once business realizes how practical this would be, these robots will become an easy sell.

I'm here to tell you, there's tons of room for innovation, improvement, and cost reduction in robotics. This is the same muse that drove the microcomputer revolution of the '80s but with eyes, arms, and legs. It's nice to work on a professional platform, but there's something magic about the hobbyist's enthusiasm that moves the medium forward!

I believe the robot revolution is going to come from the home. Consumer electronics still drive technology, but there are some wonderful things coming from labs that are finally making an appearance.

This is a great business with great people, and it is just getting started. **SV**

Two anecdotes for your amusement: When I was entering the expo, I encountered a young man coming from the nearby Server Design Summit who desperately wanted to get into the RoboBusiness expo. "My conference is so boring!" he exclaimed. I told him that he was in the wrong business and should get involved in robotics because it is definitely not boring.

Finally, at the end of the expo on my way out the door, I observed a young man working on a robot in the corner. His name was Balaji Lakshmanan and he was working on his "shopping robot" which he had demoed the day before at the Pitchfire event. In a genuine small-world moment he recognized me because he had been following the HomeBrew Robotics Club mailing list from India for the past five years. Balaji is the CEO of Geeky, Inc., and iMakeRobots. He made a robot for the Bollywood movie "Mugammodi," as well as other animatronics, educational robots, a telepresence robot, and his latest shopping 'bot.



Balaji and his shopping robot.



LANDRONE.



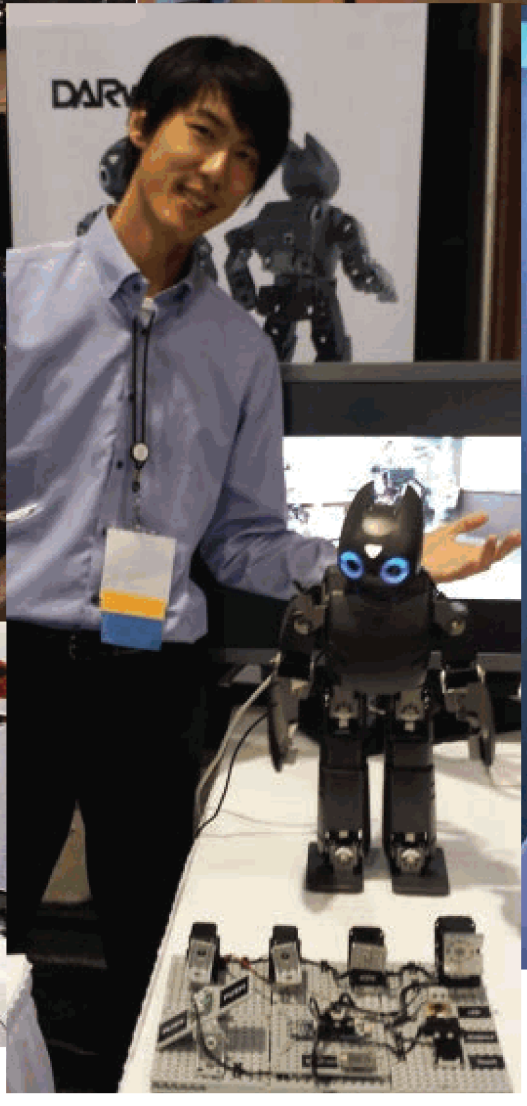
Operating a robot arm at the Harmonic booth.



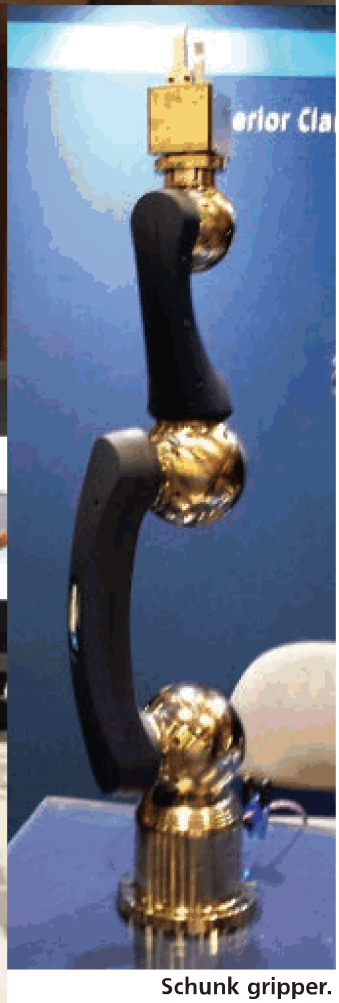
Robot forklift.



Baxter looking a little confused.



Richie shows off DARwIn-OP.



Schunk gripper.

# SPRITE

# Simple Pi Robot Interactive Testbed for Experiments

By William Henning
mikronauts@gmail.com

Post comments on this article and find any associated files and/or downloads at **www.servomagazine.com/index.php/magazine/article/january2014_Henning.**

I have been following the Raspberry Pi since before it was available — other than the sheer "WOW" factor of a credit card sized $35 computer, I've been wanting to use a Pi as the "cerebral cortex" for some of my robots.

What I really like about using the Raspberry Pi as a robot brain is that I can easily have a Wi-Fi connection to it using an inexpensive USB Wi-Fi adapter and SSH into the robot, or even run the desktop remotely. Cutting the programming cord is a huge leap forward.

Think about it — programming your robot, on your robot, from any computer, iPad, iPhone, or Android device!

I decided to make a robot controller for the Raspberry Pi that would be as simple as possible for students and hobbyists to build — one that can be used as a testbed for experimenting with robotics, and expanded as needed.

In this article, I will show you:

- How to build a simple robotics add-on shield for your Raspberry Pi using an inexpensive prototyping shield and a handful of parts.
- How to set up your Raspberry Pi so you can connect to it over Wi-Fi.
- How to write code for your Wi-Fi Pi robot.

There are many ways of building a robot (and robot controller), so I will list each major decision point, then show the alternatives I considered and the choice I ultimately made.

## Decision #1: How to interface 5V inputs and outputs to the 3.3V GPIO pins.

I wanted to interface 5V servos and 5V digital sensors to the Pi safely and as simply as possible for the lowest possible cost.

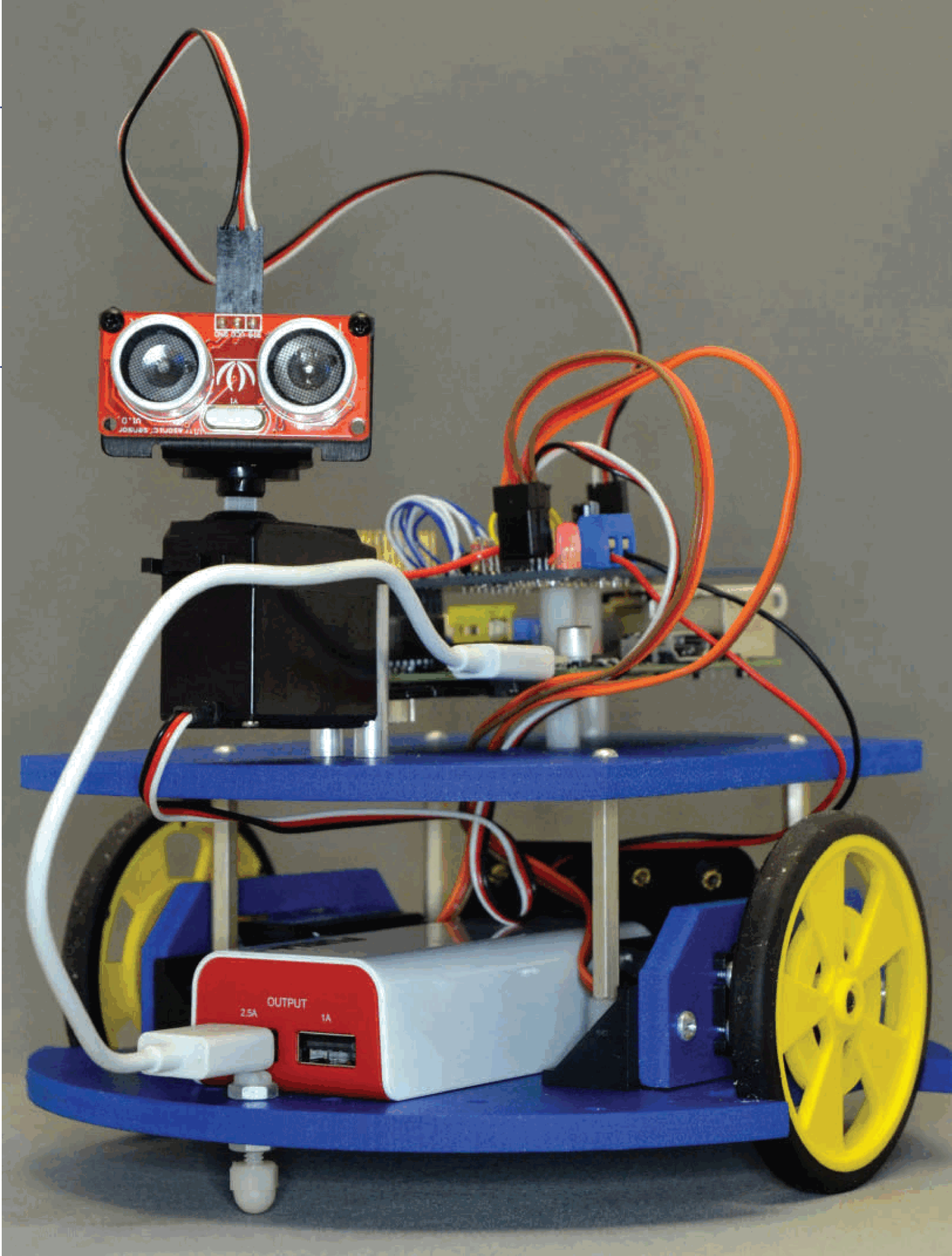
The Broadcom processor on the Pi has 3.3V GPIOs, and while servos can be controlled by a 3.3V signal, we should limit the current the servo can draw from the Pi to guard against damaging the GPIO.

What is cheaper and simpler than passive components? We have to handle:

1) Input — Reading a 5 VDC signal safely with a 3.3 VDC Pi GPIO.
   A. A voltage divider is a great approach.
   B. We can use a nice SIP bussed resistor for the resistors to ground.

2) Output — Controlling devices that expect a 5 VDC control signal.
   1. Most such devices can be driven by a 3.3V signal.
   2. The only potential concern is drawing too much current from the Pi's GPIO.
   3. A current-limiting resistor solves that.

**Photo 1:** Meet SPRITE — my first Raspberry Pi based robot. Cute little feller, isn't he?


OUTPUT
2.5A
1A

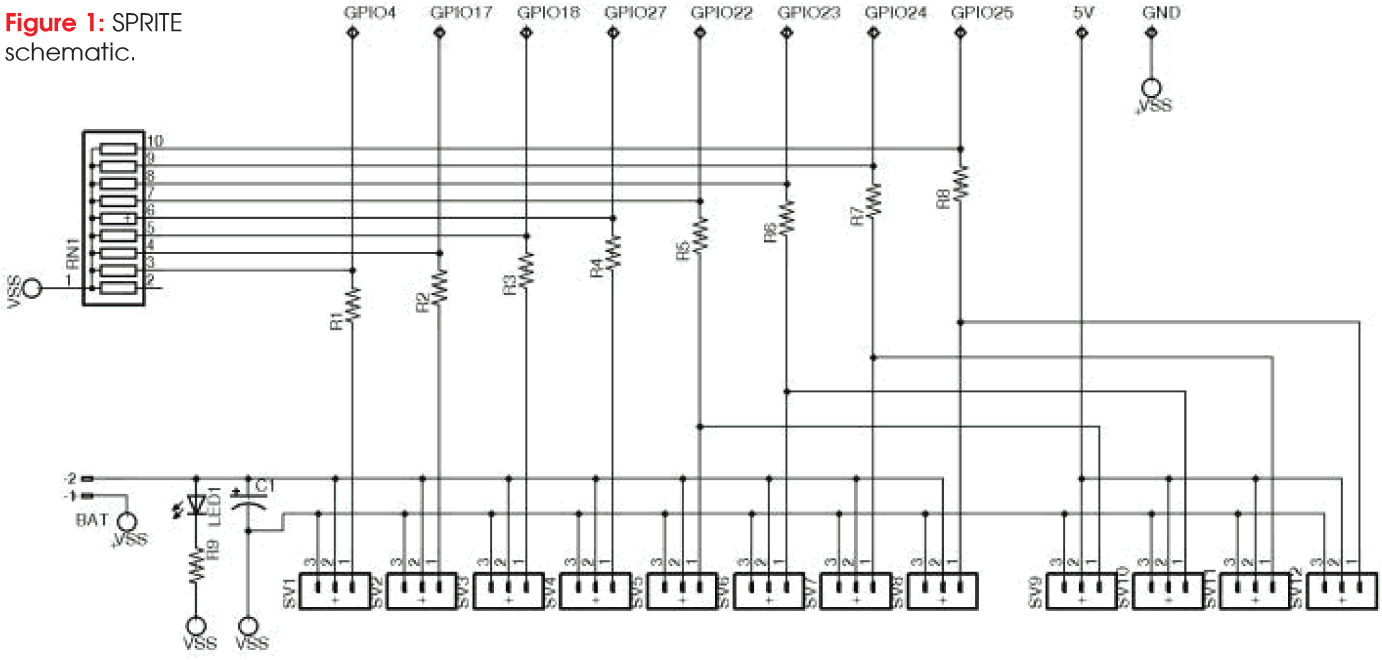



**Figure 1:** SPRITE schematic.

Using passive components is both cheaper and simpler than using level translator chips or MOSFETs.

The fly in the ointment, however, is what resistor values work best for both input and output?

Initially, I grabbed a 15K SIP and eight 8.2K resistors. It worked well for the servos and reading the simple digital inputs. Little did I know the problems I'd run into later ...

I ended up using a 4.7K SIP (RN1) and 2.4K resistors (R1-R8) for the voltage dividers, with a 470 ohm resistor (R9) for the LED. I also added a 100 µF electrolytic capacitor (C1).

You may need to change these values depending on your application. For example, if you want to drive LEDs, using a 910 ohm SIP with 470 ohm discrete resistors would be a good choice.

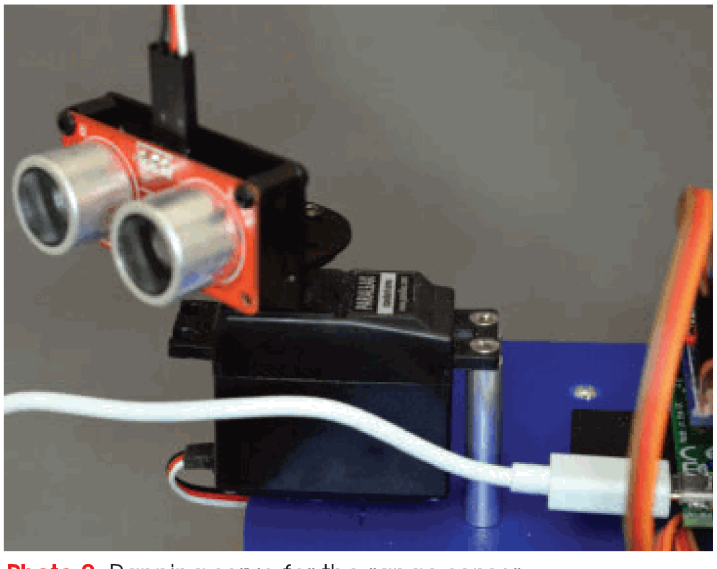


**Photo 2:** Panning servo for the range sensor.

## Decision #2: Choosing between servo, gear, and stepper motors.

I ended up using some generic continous rotation servos I had in my lab — Futaba, Parallax, and GWS are also good readily available choices. I added a standard Parallax servo for panning the range sensor.

There is a wide range of servos on the market — just make sure whichever continous rotation servo you buy has a "centering" potentiometer so you can set the center position of the servo. You can compensate for servos without centering potentiometers in software, but it is simpler if you don't do it this way.

While servos are slightly more expensive than gear motors, we avoid having to build or buy a motor driver which is important in order to minimize the assembly work required before being able to use a functioning robot.

Stepper motors would require an external controller or more I/Os and a driver chip. I wanted to avoid the complexity that using stepper motors would introduce.

I used yellow Solarbotics wheels with the drive servos, so in the future I can add my SirMorph sensors as wheel encoders. Besides, I like how the yellow wheels look with the blue chassis.

## Decision #3: Power sources for the Raspberry Pi and the motors.

The Pi needs a regulated 5V power supply; one that can deliver at least 1.5A if you are not using a powered

hub and are using a USB Wi-Fi dongle.

I chose to use a regulated power bank: an external battery marketed for use with charging and running cell phones and tablets. It has 5,200 mAh capacity for its internal 3.7V battery that translates to about 3.6 amp-hours at 5V. So, I can expect two hours (or more) of battery life running a Raspberry Pi with a USB Wi-Fi adapter.

Servos are not as picky about power and can usually run from 4V-6V. For the sake of simplicity, a separate 4xAA battery pack will be used to drive the servo motors and 5V sensors. By using NiMH rechargeable batteries, we ensure the 5V sensors will not be damaged.

There are definite advantages to using a separate power source for the Raspberry Pi and the motors:

- Avoid introducing electrical noise to the Pi.
- Sensors can run off the "clean" Pi power supply.
- Eliminate potential brown-outs which would cause the Pi to reboot.
- A longer run life for SPRITE is a bonus.

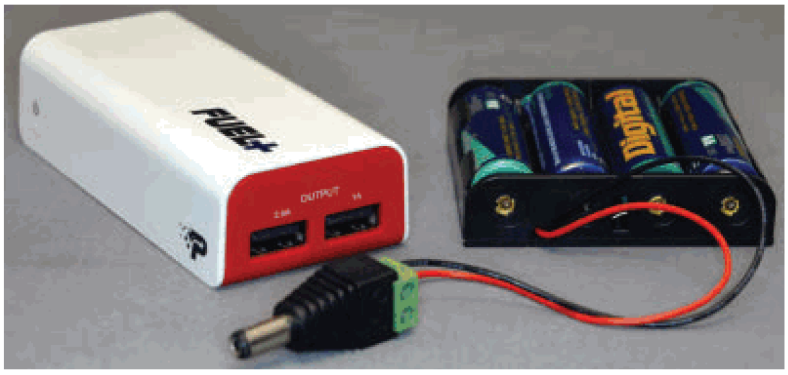



**Photo 3:** USB power bank with 2.5A output and 4xAA battery holder with NiMH batteries.

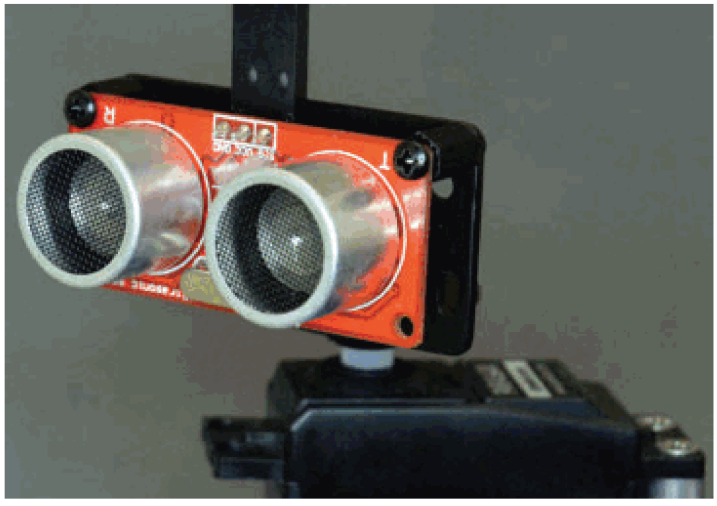


**Photo 5:** SeeedStudio ultrasonic range finder on Lynxmotion sensor bracket.

## Decision #4: Picking a chassis.

One of my favorite chassis is the one made by Parallax for the Boe-Bot. Unfortunately, I needed more room than it could provide for the two sets of batteries, and I also wanted more space for breadboarding additional circuits.

I decided to use Gordon McComb's inexpensive Ardubot chassis which was written about originally in the November 2010 issue of *SERVO*, followed by a recent update series that started in the August 2013 magazine. The two decks provide plenty of space for the batteries, Raspberry Pi, and add-ons, and the 1/4" expanded PVC is easy to drill for the mounting holes for the Pi. (I already had two to work with — they were drilled for an earlier experiment.)

I used two M3 18 mm + 6 mm standoffs at each hole, as they work great with my stacking headers. You can get your Ardubot chassis at **www.budgetrobotics.com/category/Robot-Chassis-Kits-161**. Gordon also sells optional add-on decks, so if you need more space, you can always add another deck!

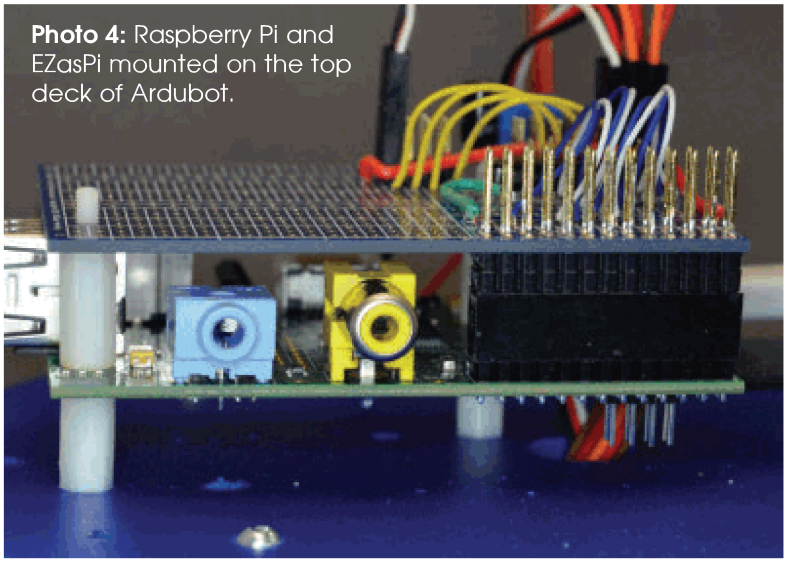


**Photo 4:** Raspberry Pi and EZasPi mounted on the top deck of Ardubot.

## Decision #5: Picking an ultrasonic range sensor.

I chose the $15 SeeedStudio ultrasonic range sensor based on cost, ease of use, and only needing a single I/O. The Parallax Ping))) sensor is also an excellent choice with a longer sensing range, but it costs almost twice as much.

When I hooked up the range sensor, it did not work. Turns out I was a wee bit aggressive in current-limiting the GPIOs on the Pi — so much so that it would not trigger the ultrasonic transducer!

After some experimentation, I determined that using a 4.7K SIP with 2.4K resistors worked well for both the ultrasonic range sensor and for driving the servos. Remember to power the sensor from the Pi's regulated 5V — not the battery pack used for the

servos! In case you are wondering why I didn't use an analog IR range sensor, it's because I wanted to avoid having to add an analog-to-digital converter at this point – my overall goal for SPRITE was simplicity.

I also decided against using whiskers (bump sensors). Robots are kid magnets, and very young children might manage to injure themselves by getting poked by the whiskers.

## Setting up your Raspberry Pi

**Step 1:** Let's get your Raspberry Pi running.

There is a great Quick Start Guide at **www.raspberrypi.org/wp-content/uploads/2012/04/quick-start-guide-v2_1.pdf**.

If you follow that guide, choose to install Raspbian as your OS from NOOBS.

**Step 2:** Install a text editor you are used to (if you like Nano or Vi, you can skip this step).

What I don't like is the included Nano editor. I am old school, and I still have the pre-historic Wordstar control keys hard-wired in my brain. Joe is a good simple text editor I'm used to.

In this article, when you see:

*Type "insert text here"*

then you should enter the indicated text on the Pi console (or terminal or SSH session) and press return.

*Type "sudo apt-get install joe"*

**Step 3:** Select a good Wi-Fi adapter for your Pi.

This is critical. There is a good list of adapters known to work at **http://elinux.org/RPi_USB_Wi-Fi_Adapters**.

I strongly recommend that you choose an adapter that does not require a powered hub or compiling kernel modules. Spending a few extra bucks on the adapter can save you hours of work.

Of the adapters I have in my lab, I like the Nets WF-2111s best as they work without a powered hub. If you plug it in when the Pi is already running, it will likely reboot your Pi but will work fine after that. My suggestion is plug it into the Pi before powering up.

**Step 4:** Set up the Wi-Fi.

A good tutorial on setting up Wi-Fi on your Pi can be found at **http://learn.adafruit.com/adafruits-raspberry-pi-lesson-3-network-setup/setting-up-wifi-with-raspbian**.

**Step 5:** Name your Pi.

Since I have multiple Pis, I give each one a different hostname.

Edit */etc/hosts* to change the host name in it:

*Type "sudo joe /etc/hosts"*

Change the line that reads:
"127.0.1.1 raspberrypi"
to read:
"127.0.1.1 mypiname"

Next change */etc/hostname* to reflect the new name:

*Type "sudo joe /etc/hostname"*

Change 'raspberrypi' to 'mypiname'

Then, execute the *hostname.sh* system script:

*Type "sudo /etc/init.d/hostname.sh"*

and reboot.

*Type "sudo reboot"*

You can find a more verbose version of how to change your hostname at **www.howtogeek.com/167195/how-to-change-your-raspberry-pi-or-other-linux-devices-hostname/**.

I ended up having to make a few more changes to get everything working right, so I suggest you modify your */etc/network/interfaces* and */etc/wpa_supplicant/wpa_supplicant.conf* to match.

Here is my */etc/network/interfaces* file:

```
auto lo

iface lo inet loopback
iface eth0 inet dhcp

allow-hotplug wlan0
iface wlan0 inet dhcp
wpa-conf /etc/wpa_supplicant/wpa_supplicant.conf
iface default inet dhcp
```

Here is my */etc/wpa_supplicant/wpa_supplicant.conf* file (set up for WAP2 encryption):

```
ctrl_interface=DIR=/var/run/wpa_supplicant GROUP=netdev
update_config=1

network={
    ssid="yourSSID"
    psk="yourpassword"
    proto=RSN
    key_mgmt=WPA-PSK
    pairwise=CCMP
    auth_alg=OPEN
}
```

If it doesn't work, you likely have a password or encryption mis-match. If SSH is not enough for you, you can install XRDP by running the following command:

*Type "sudo apt-get install xrdp"*

There are SSH and RDP clients for all phones, tablets, and computers.

You can find your Pi's IP address by looking on your router's "Attached Devices" screen if it has one, or by connecting a keyboard and monitor to your Pi. If all else fails, you can assign your Pi a static IP address.

Enjoy your Wi-Fi connection!

## To summarize what was decided so far:

1. Use a voltage divider for 5V to 3.3V bi-directional interfacing.
2. Use continous rotation servos for the drive motors and a standard servo for panning.
3. Use a regulated 5V power bank to power the Pi and a 4.8V NiMH battery pack for the motors.
4. Use an Ardubot chassis.
5. Use a SeeedStudio ultrasonic range sensor.

## Building the Simple Raspberry Pi Robot Controller

I will freely admit that I am not particularly fond of cutting and stripping a lot of wire, so I designed the Mikronauts "EZasPi" prototyping board specifically to make it very simple to build circuits that need to connect to servo connectors, headers, screw terminals, and 300/600 mil DIP chips. The short bus lines do most of the wiring for you, as long as you place the components carefully.

First, I added the upper resistors in the voltage divider for all eight Pi GPIOs that I wanted to bring out to a servo header. The placement of the parts is critical in order to minimize the number of jumpers that will be needed.

Next, I added the 4.7K SIP resistor network, placing the common lead farthest from the edge of the prototyping board. The 3x8 servo header was next; I located it so that two rows of pins were placed into two of the power busses, and the third pin into the bus connecting to the corresponding resistor.

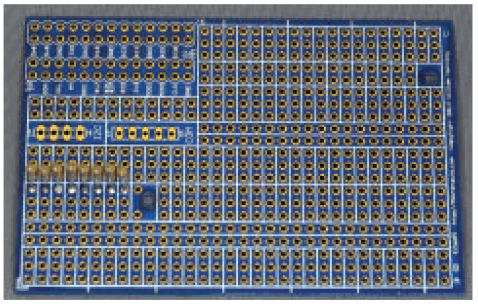


**Photo 6:** EZasPi prototyping board.

## SPRITE Demonstration Code

My demonstration program for SPRITE is unimaginatively called *demo.c*. After initializing the robot, it presents a simple text menu of actions:

| | |
|---|---|
| f{n} | Go forward |
| b{n} | Go backward |
| l{n} | Turn left |
| r{n} | Turn right |
| s | Sonar scan using the panning servo |
| w | Random walk with obstacle avoidance |
| q | Quit the demo |

The forward/backward/left/right commands take an optional single digit argument which specifices how many seconds to do the action for. If a digit is not specified, one second is assumed.

The sonar scan demonstrates using the panning head to look in different directions, and it shows the range to the closest object at each servo position it tries.

The random walk code keeps going forward until the range sensor finds something closer than 30 cm. Then, it turns left in place until it finds a direction with at least 50 cm to travel.

You will notice that if you go forward or reverse, the robot may not travel in a straight line. This happens due to variations in servo motors, and can largely be compensated for by adding a compensation factor to the code.

```
while (1) {
  while (last_range > 30) {
   ping();
   delay(100);
    servo(LMOTOR, 500);
   servo(RMOTOR, 3000-500);
  }
  puts("Obstacle detected");
  while (last_range < 50) {
   ping();
   delay(100);
   servo(LMOTOR, 500);
   servo(RMOTOR, 500);
  }
}
```

**Listing 1:** Random walk with obstacle avoidance.

## How to Program SPRITE

You can program SPRITE in a number of ways:

1. Local console using a USB keyboard and HDMI monitor.
2. Local desktop using a USB keyboard, mouse, and HDMI monitor.
3. Remote console using SSH.
4. Remote desktop using the RDP protocol.

If you use a local interface, just plug in your keyboard, mouse, and monitor, and type away. This works, but you have to plug in a keyboard and monitor (and a mouse for a graphical desktop, so if you are using Wi-Fi you also need a powered hub), then shut down, unplug it all, run the test, re-plug ... rinse and repeat for debugging ... it's very time consuming.

My personal preference is a remote console over SSH. I use the excellent free PuTTY SSH client, and I connect to the dynamic IP address my router assigns to SPRITE. Fortunately, my router has a page that shows the IP address of attached devices, so I do not have to use a static IP address (and the more complicated Wi-Fi configuration it requires). You can get the latest version of PuTTY at **www.chiark.greenend.org.uk/~sgtatham/putty/download.html**. Android and iOS SSH apps are available in their respective markets, and Linux distributions tend to come with SSH clients pre-installed.

You can easily connect to a remote Raspbian desktop running on SPRITE. All you need to do is install XRDP as shown earlier, and use the remote desktop client supplied with Windows (or any other RDP client) or the free clients available for Android and iOS devices. You can then open a terminal on the remote desktop and away you go!

You can use any text editor you want to use to write C/C++ code for SPRITE — Vi, Nano, and Joe are just a few examples of console based editors.

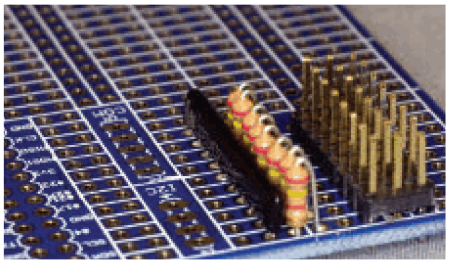
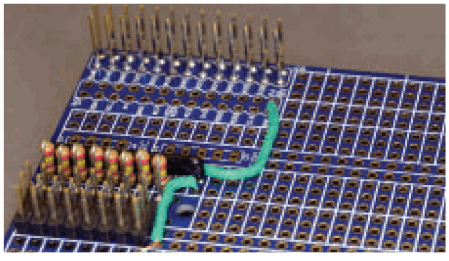


**Photo 7:** Resistors and servo header.



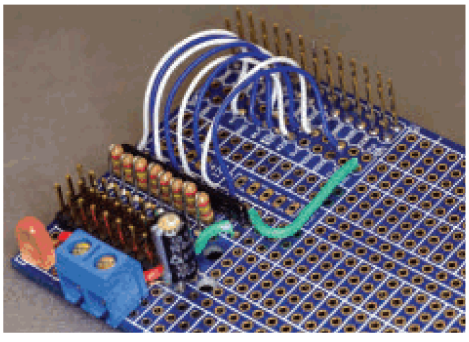
I added my stacking header next. Make sure the female end faces down towards the Pi board because desoldering that connector would likely ruin it.

I then added a ground wire from the Pi header area to one side of the common pin of the SIP resistor, and another wire to the ground bus. A small jumper connected a small bussed area to ground to prepare for a screw terminal.

A red LED indicates when the motor batteries are connected. It's connected to the positive side of the screw terminal (on the left) and to ground through a 470 ohm resistor. Note the ground wires to the SIP resistor from the Pi header and the electrolytic capacitor connected to battery power and ground.

**Photo 8:** Stacking header and ground wires.

**Photo 9:** LED, screw terminal, and GPIO wiring.



| Item | Qty | Supplier | Part# | Link | Notes |
|---|---|---|---|---|---|
| EZasPI (includes stacking header) | 1 | Mikronauts | EZASPI-KIT | http://Mikronauts.com | Designed for ease of use. |
| 4x3 pin servo header | 1 | Mikronauts | SERVO4CON | http://Mikronauts.com | Can substitute 3 pieces of 1x4 male pin header; 3x Mouser 571-826629-4. |
| 8x3 pin servo header | 1 | Mikronauts | SERVO8CON | http://Mikronauts.com | Can substitute 3 pieces of 1x8 male pin header; 3x Mouser 571-826926-8. |
| 4.7K 9 resistor bussed SIP10 | 1 | Digi-Key | 987-1267-ND | www.digikey.com | Can substitute 4K7 8 resistor SIP9. |
| 2.4K 5% 1/4W resistor | 8 | Digi-Key | CF14JT2K40CT-ND | www.digikey.com | 1/6 watt or higher, but do not substitute value. |
| Two-screw terminal block | 1 | Digi-Key | CF14JT470RCT-ND | www.digikey.com | You could solder the battery wires instead. |
| Red LED | 1 | Digi-Key | 365-1189-ND | www.digikey.com | Any 3 mm-5 mm red LED. |
| 470 ohm resistor | 1 | Digi-Key | CF14JT470RCT-ND | www.digikey.com | 1/6 watt or higher would work. |
| 100 µF 10V electrolytic capacitor | 1 | Digi-Key | 399-6600-ND | www.digikey.com | Any 47 µF and up capacitor rated for 10V or higher. |
| AA battery holder | 1 | Digi-Key | BC4AAW-ND | www.digikey.com | You can get these anywhere — including RadioShack. |
| Nylon M3 18 mm + 6 mm standoff | 4 | Mikronauts | M3-18-6-STDOFF | http://Mikronauts.com | You can use other standoffs of the correct height. |
| Nylon M3 25 mm or more standoff | 2 | Mikronauts | M3-SERVO-STDOFF | http://Mikronauts.com | Used to mount pan servo. |
| Nylon M3 12 mm screw | 4 | Mikronauts | M3-12-SCR | http://Mikronauts.com | |
| Nylon M3 nut | 4 | Mikronauts | M3-NUT | http://Mikronauts.com | |
| SPRITE Kit | 1 | Mikronauts | SPRITE-KIT | http://Mikronauts.com | Includes items 1-14 above; see http://Mikronauts.com/robot-zoo/sprite for details. |
| **Major Components** | | | | | |
| Raspberry Pi | 1 | Newark | RASPBRRY-MODB-512M | www.newark.com | The Model-A may work, but I have not tried it. |
| EZasPI SPRITE kit | 1 | Mikronauts | SPRITE-KIT | http://Mikronauts.com /robot-zoo/sprite | See link for details. |
| Ardubot | 1 | Budget Robotics | Robot-Chassis-Kits-161 | www.budgetrobotics.com | Chassis must be big enough for everything and be servo driven. |
| Wi-Fi adapter | 1 | Tp-link | Low power USB | www.newegg.com | Netis WF-2111; see **http://elinux.org/RPi_USB_Wi-Fi_Adapters** for list of compatible adapters; choose one that does not need a powered hub. |
| Parallax standard servo | 1 | Digi-Key | 900-00005-ND | www.digikey.com | Other standard servos would work. |
| Parallax continuous rotation servo | 2 | Digi-Key | 900-00008-ND | www.digikey.com | Other continuous rotation servos would work. |
| Servo wheels | 2 | RobotShop | RB-Sbo-86 | www.robotshop.com | They have other colors, as well. |
| SeeedStudio ultrasonic range finder | 1 | RobotShop | RB-See-90 | www.robotshop.com | You can substitute the Parallax Ping))) sensor. |
| Servo extension cable | 1 | RobotShop | RB-Pol-180 | www.robotshop.com | This one is long ... try to find a shorter one. |
| Lynxmotion sensor housing | 1 | RobotShop | RB-Lyn-75 | www.robotshop.com | Any sensor mount will do. |
| Patriot power bank | 1 | NCIX | PCPB52002 | www.ncix.com | If you substitute, make sure the battery can supply regulated 5V 2A. |
| NiMH 4xAA batteries and charger | 1 | NCIX | ECH420 | www.ncix.com | Or equivalent, minimum 1800 mAh suggested. |

You will also need some standard tools: screwdrivers, pliers, wire cutters, wire stripper, soldering iron, hookup wire, and solder.

The blue and white jumper wires connect to the eight Raspberry Pi GPIOs that are not used for I²C or SPI. Note the hole where I cut the power bus.

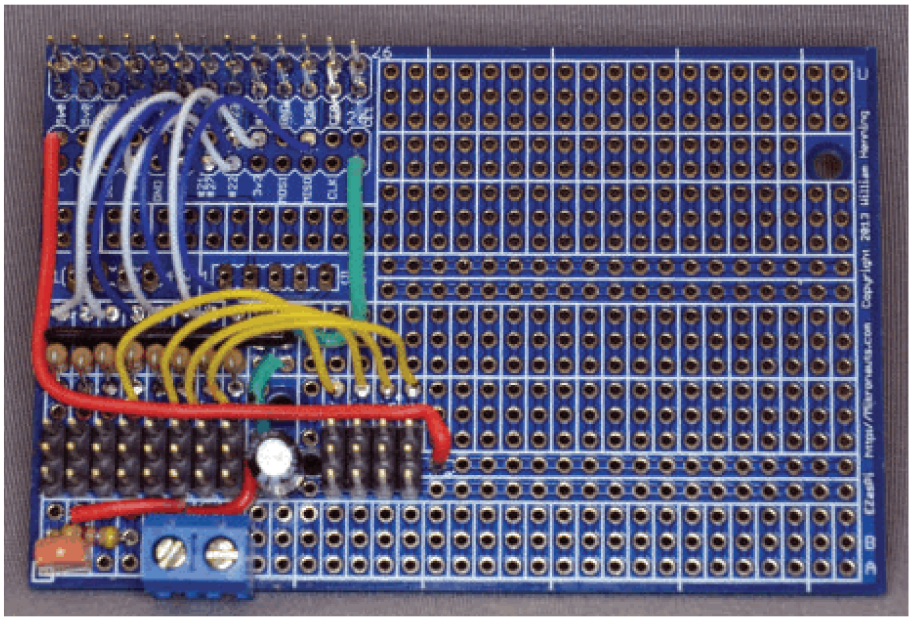


**Photo 10:** Completed SPRITE board.

## Are we there yet???

Almost! First, I used a Dremel to drill out one of the holes on the power bus. This isolated the battery powered section. I then used the long red jumper to connect the Pi's 5V to the non-battery power bus.

Adding a 3x4 servo header and connecting it with the right-most four battery powered signals allows me to add things like SeedStudio's range sensor that need a regulated power supply on the smaller header.

## Yes! We are finally there!

Note: I deliberately avoided adding jumpers to the bottom of the board – in fact, there is only one jumper down there; the bent lead of the LED's resistor is tack-soldered to the ground terminal on the header above it.

Just look at all the space we have left for additional circuitry – or a even small breadboard! Okay, now that the hardware is ready, it's time to get the Raspberry Pi loaded with all the needed software and the demo program.

## Controlling Servos and Reading Digital Inputs

There are several excellent GPIO libraries for the Pi. Initially, I was going to use ServoBlaster, but as it often requires having to build a kernel module (pre-compiled modules are not available for up-to-date Raspberry Pi kernels), I changed my mind.

WiringPi looked great, however, its current PWM implementation would not have given me the level of control I wanted over the servos I am using for the robot.

I ended up using "pigpio" – an excellent, easy to use library for C / C++ found at **http://abyz.co.uk/rpi/pigpio**.

Controlling the servos and reading digital inputs is a piece of Pi with pigpio. (You thought I'd say a piece of cake, didn't you?) There was only one minor gotcha with pigpio: the way it measures a pulse length. The handler has to NOT measure the length of the pulse trigger!

Fortunately, simply adding a guard variable around the echo measurement code solved that problem. Once you have your Raspberry Pi running, installing pigpio is easy:

Type the following lines into the console:

*wget http://abyz.co.uk/rpi/pigpio/pigpio.tar*
*tar xvf pigpio.tar*
*cd PIGPIO*
*make*
*make install*

You can find SPRITE related material including the demo source code at **http://mikronauts.com/robot-zoo/sprite**/. Click on *sprite-demo.c* to download the code. After installing pigpio, compiling the SPRITE demonstration software is very easy:

*Type "cc -o sprite-demo sprite-demo.c -lpigpio -lrt -lpthread"*

To execute the demo:

*Type "sudo ./sprite-demo"*

## Wrapping Up

I hope you enjoyed this article and that you construct your own Raspberry Pi based robot. I really enjoyed building SPRITE, and I will continue to improve it over time.

In the near future, I will add:

1. An analog-to-digital converter so I can use sensors that output an analog signal.
2. A digital compass so SPRITE can use absolute and relative compass headings.
3. A higher capacity battery pack for the motors.
4. A simple web browser based interface to the robot.
5. More demonstration code.

And much, much more!

In case you want a SPRITE of your own but prefer not to build it on a prototyping board, Mikronauts should have a SPRITE printed circuit board available – no need to cut and solder jumpers.

I'm looking forward to getting your feedback on this article at the *SERVO* forum. SV

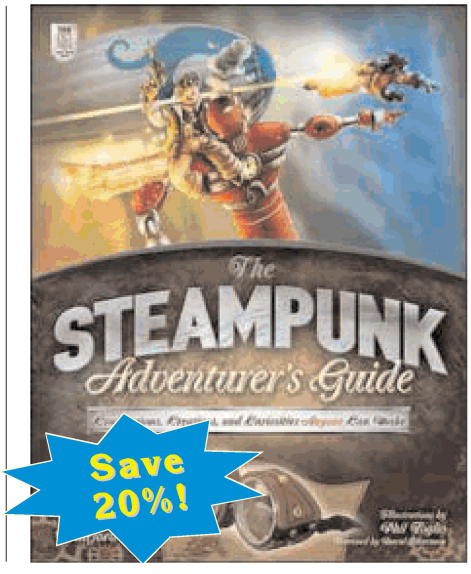
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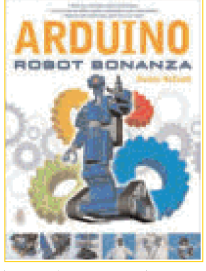



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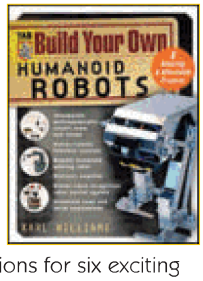
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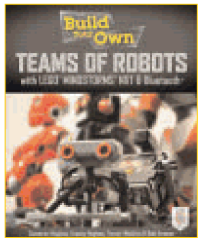
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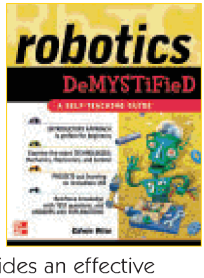
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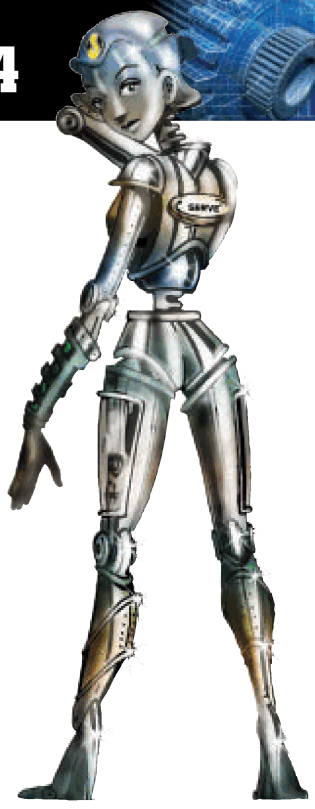
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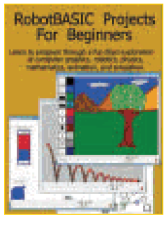
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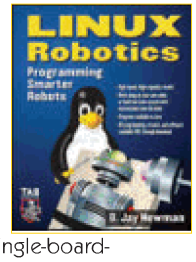


If you want to learn how to program, this is the book for you. Most texts on programming offer dry, boring examples that are difficult to follow. In this book, a wide variety of interesting and relevant subjects are explored using a problem-solving methodology that develops logical thinking skills while making learning fun. RobotBASIC is an easy-to-use computer language available for any Windows-based PC and is used throughout the text.

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by D. Jay Newman

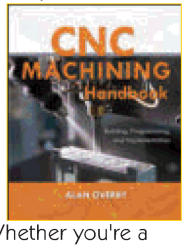


If you want your robot to have more brains than microcontrollers can deliver — if you want a truly intelligent, high-capability robot — everything you need is right here. *Linux Robotics* gives you step-by-step directions for "Zeppo," a super-smart, single-board-powered robot that can be built by any hobbyist. You also get complete instructions for incorporating Linux single boards into your own unique robotic designs. No programming experience is required. This book includes access to all the downloadable programs you need.

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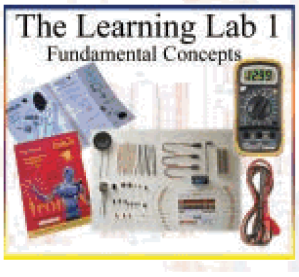
## CNC Machining Handbook: Building, Programming, and Implementation

by Alan Overby

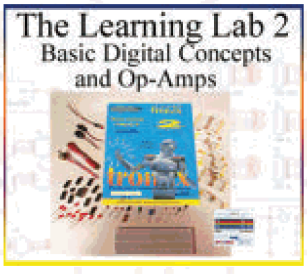


The *CNC Machining Handbook* describes the steps involved in building a CNC machine and successfully implementing it in a real world application. Helpful photos and illustrations are featured throughout. Whether you're a student, hobbyist, or business owner looking to move from a manual manufacturing process to the accuracy and repeatability of what CNC has to offer, you'll benefit from the in-depth information in this comprehensive resource. **$34.95**

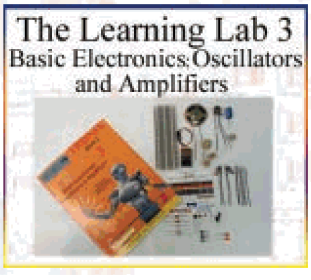
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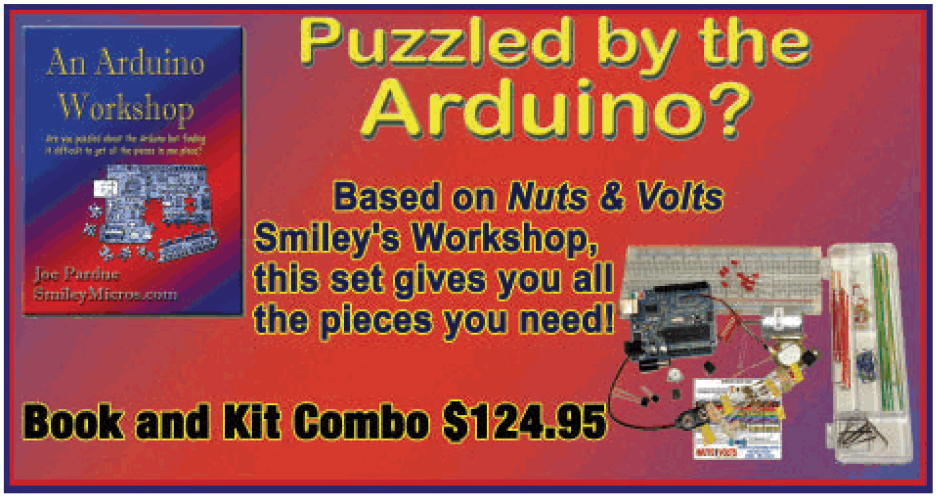

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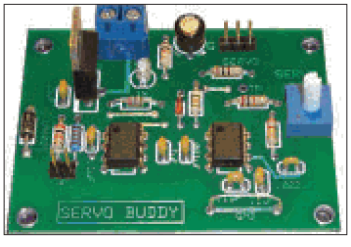






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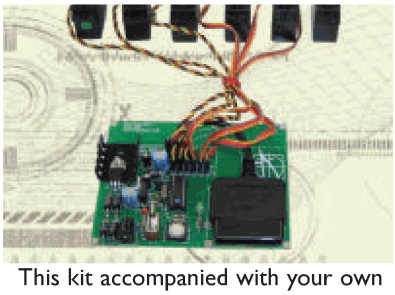


**From the article "Build the 3D LED Matrix Cube" as seen in the August 2011 issue of *Nuts & Volts Magazine*.**

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# Windows 8 Tablets

By John Blankenship and Samuel Mishal

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**Last month, we explored the premise that a Windows 8 tablet has the potential for being the ultimate robot controller. This month, we will examine two applications to demonstrate how tablet sensors can be integrated into a robotic project. The first project will make the tablet act as a steering wheel so it can be used to drive a robot throughout its environment. The second will use the tablet's compass to maintain the robot's heading as it moves forward.**

Windows 8 tablets have many internal sensors that can be valuable for robotic projects. Last month, we showed how a free utility program can provide access to these sensors from almost any programming language. The only requirements are that the language can communicate with the clipboard and manipulate file names.

In this portion of our series, we will examine two simple examples that demonstrate how to access the sensor data and utilize it to control a robot. We'll want to mount the tablet on the robot itself so that the sensor readings are indicative of the robot's current orientation. Most of our projects will certainly deal with this option.

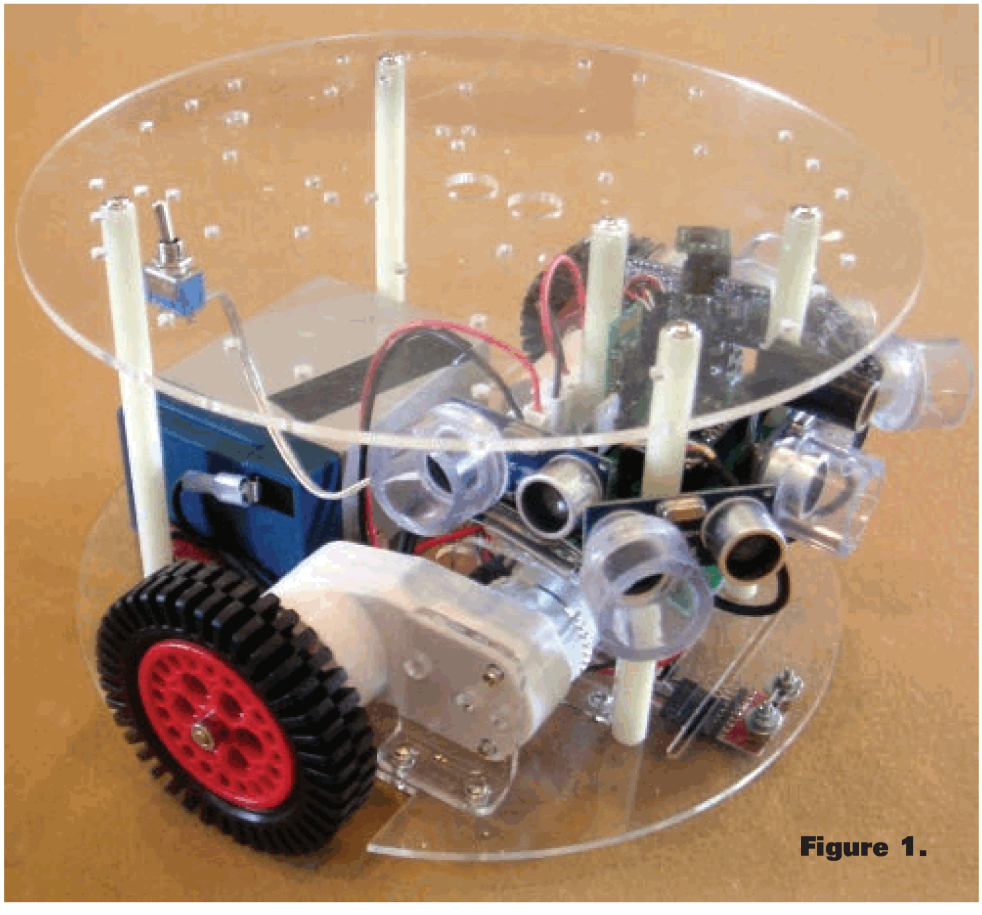


**Figure 1.**

## The Tablet as a Wheel

As mentioned, for our first

# Using the Orientation Sensors Part 2

example, we'll have the tablet act as a steering wheel so we can drive a robot around the room. Turning the tablet left and right should make the robot turn in the same manner. Likewise, tilting the tablet forward or backward should move the robot forward and in reverse. The amount the tablet is tilted should affect the amount of turn and the speed of the movements.

Obviously, we don't want the tablet to be tethered to the robot for this project, so we will use a Bluetooth connection so the robot can roam freely. As discussed in Part 1, a tablet's Bluetooth link can communicate with a motor controller module, an I/O card, or even a microcontroller that interfaces with the robot's motors. These are all great options if you want to homebrew your entire project.

For our examples, we'll focus the attention on the tablet itself and minimize the efforts needed to interface with motors and other sensors, so we'll use RobotBASIC to control the RB-9 robot shown in **Figure 1**. Notice the PCB (printed circuit board) mounted between the two layers. It contains the RobotBASIC Robot Operating System (RROS) which is one of the easiest ways of building and controlling a full-featured robot. (We described this back in the September 2012 issue.) The RROS system and the RB-9 chassis are available from **www.RobotBASIC.org**.

While we think the RB-9 is an excellent platform, we also realize others will want to duplicate our work with robots they already have. All the programs for these tablet projects will be written in RobotBASIC because its pseudocode-like syntax should make it easy to export the principles to other languages.

Our steering-wheel program (shown in **Figure 2**) is composed of two basic parts. The beginning of the program obtains sensor data that indicates how the tablet is tilted, and converts that data into three parameters

```
main:
  // first initialize the RROS
  #include "RROScommands.bas"
  gosub InitCommands
  // change offsets below as needed
  call InitSensors(0,0,0,0) // see last month
  gosub InitConstants // initialize constants
  gosub InitRB9robot // initialize the robot
  while rRange()>24 // loop while no objects detected
    // FIRST DETERMINE THE MOVEMENT PARAMETERS
    call Orientation(Tilt1, Tilt2, Tilt3, Heading)
    // the following calculations assumes the readings
    // zero in the normal position (offset if needed)
    if within(Tilt1,-10,10) then Tilt1=0
    if within(Tilt2,-10,10) then Tilt2=0
    Speed=abs(Tilt1)*3
    if Speed>99 then Speed=99
    // Speed is used to control the speed all
    // movement except for rotates
    RotateSpeed = abs(Tilt2)*3
    If RotateSpeed>99 then RotateSpeed=99
    TurnAmount=abs(Tilt2)*3
    if TurnAmount>99 then TurnAmount=99
    TurnAmount=100-TurnAmount
    Direction=255 // default (stop) condition
    if Tilt1<0 and Tilt2>0 then Direction=ForwRight
    if Tilt1<0 and Tilt2<0 then Direction=ForwLeft
    if Tilt1>0 and Tilt2>0 then Direction=RevRight
    if Tilt1>0 and Tilt2<0 then Direction=RevLeft
    if Tilt1<0 and Tilt2=0 then Direction=Forw
    if Tilt1>0 and Tilt2=0 then Direction=Rev
    if Tilt1=0 and Tilt2>0 then Direction=RotR
    if Tilt1=0 and Tilt2<0 then Direction=RotL
    // NOW USE PARAMETERS TO CONTROL THE ROBOT
    // set robot's speed
    rCommand(SetSpeed,Speed)
    rCommand(SetSlowDownSpeed,RotateSpeed)
    // create the desired movement
    // (for other platforms, place your code
    // below each decision statement)
    if Direction=Forw
      rForward 1
    elseif Direction=Rev
      rForward -1
    elseif Direction=RotR
      rTurn 1
    elseif Direction=RotL
      rTurn -1
    elseif Direction=ForwRight
      rCommand(Drive,Direction+TurnAmount/2)
    elseif Direction=ForwLeft
      rCommand(Drive,Direction+TurnAmount/2)
    elseif Direction=RevRight
      rCommand(Drive,Direction+TurnAmount/2)
    elseif Direction=RevLeft
      rCommand(Drive,Direction+TurnAmount/2)
    elseif Direction=Stop
      rForward 0
    endif
  wend
end
```

**Figure 2.**

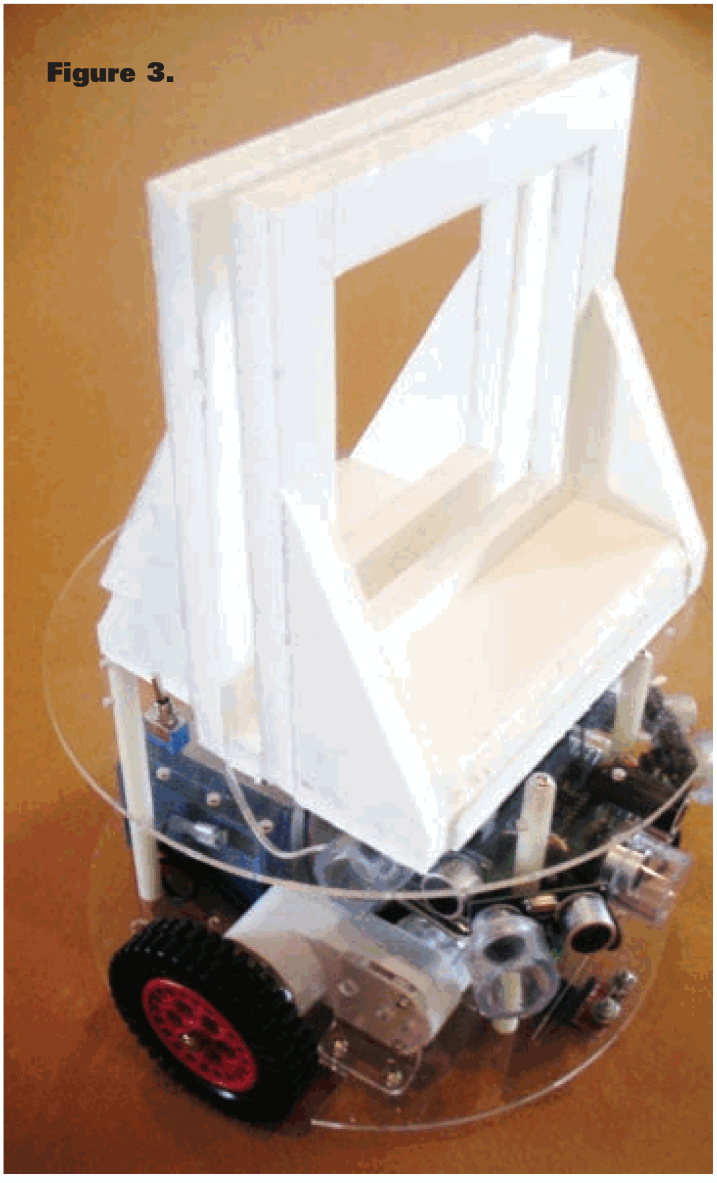


**Figure 3.**



**Figure 4.**

specifying how the robot should respond. The second portion of the program uses the parameters to actually control the robot's actions. Dividing the functionality this way makes it much easier to port the algorithm to other platforms.

After initialization, the program begins by calling the *Orientation* routine discussed last month to obtain the tilt and compass data from the tablet's sensors. The amount of forward/backward tilt is stored in *Tilt1* and the side-to-side inclination in *Tilt2* (assuming a landscape orientation of the tablet). Notice that the tilt readings are set to zero within a range of ±20° around the normal position which is a flat, face-up orientation unless offsets are provided in the call to *InitSensors*.

Next, the amount of forward-backward tilt is converted to a desired speed parameter (*Speed*) ranging from 0% to 99% by multiplying the absolute value of *Tilt1* by 3. This means the full range can be obtained by tilting the tablet ±33°. In a similar manner, the side-to-side tilt is converted into a percentage of the amount of turn the robot should make (*TurnAmount*).

Finally, the various combinations of the two relevant tilts are used to establish the desired movement by assigning the variable *Direction* the value of a predetermined constant. As an example, if the tablet is not tilted forward or backward, but is tilted to the right, the variable *Direction* is set to *RotR*, indicating the robot should rotate to the right.

The details of how these parameters are used is shown in the second half of the main program in **Figure 2**. The implementation is very easy because of the integration of the RROS hardware with RobotBASIC's built-in commands. Let's look at these commands.

The command *rForward* causes the RROS hardware to move the robot forward or backward if a negative parameter is used. The *rTurn* command causes the robot to rotate right or left (negative parameters). The remaining turning motions can be handled in various

ways, but RobotBASIC offers *rCommands* that provide solutions for specific problems such as this one.

Each *rCommand* has two parameters — the first of which specifies a function or action to be taken. In this case, the action is to *drive* the robot in one of four arcing motions (forward-right, forward-left, reverse-right, or reverse-left). The second parameter in the command is an eight-bit byte that further defines the requested movement. Since we only have eight bits at our disposal, the data for this *rCommand* has to be encoded to allow it to fit.

The first two bits in the byte specify which of the above actions to take. The remaining six bits specify the severity of the arc with the value indicating the speed of the slower wheel as a percentage of the speed of the faster wheel. With only six bits, we cannot pass the percentage of 0-99, so the command assumes the value passed is half of the desired amount. This limits the resolution to 2%, but that is still a very small variation in the robot's motion.

The important point is how easily the turning behaviors can be implemented using this RROS command. The controlling parameter is formed by adding one of four predefined constants (*ForwRight*, *ForwLeft*, *RevRight*, and *RevLeft*) to half of the turning parameter *TurnAmount*.

If you are implementing this project on a different platform, the first portion of the program should not have to be altered at all; the second portion should be easy to modify by just substituting code that moves your robot in the appropriate manner.

## Mounting the Tablet

For our second example, the tablet will be mounted on the robot allowing the sensor data to be indicative of the orientation of the robot itself. Ideally for a finished project, the robot would be designed to house the tablet in an attractive manner. For our experimentation, we just needed a quick and functional solution.

**Figure 3** shows a holding bracket for the tablet that we constructed from foam board using only a razor blade and white glue. The details of the construction will depend on the robot and tablet you use. Take care to ensure that the bracket does not obstruct the camera's view as we will be using it in next month's project.

Our bracket allows the tablet to be mounted on the RB-9 chassis in either the portrait (**Figure 4**) or landscape mode (**Figure 5**). Both options work well for demonstrating a finished project, but we quickly found we needed an alternative mounting during the development phase.

**Figure 6** shows another foam board bracket that holds both the tablet and the lightweight keyboard dock as shown in **Figure 7**. While this arrangement is far less attractive, it allows programs to be easily modified and immediately tested without constantly connecting and

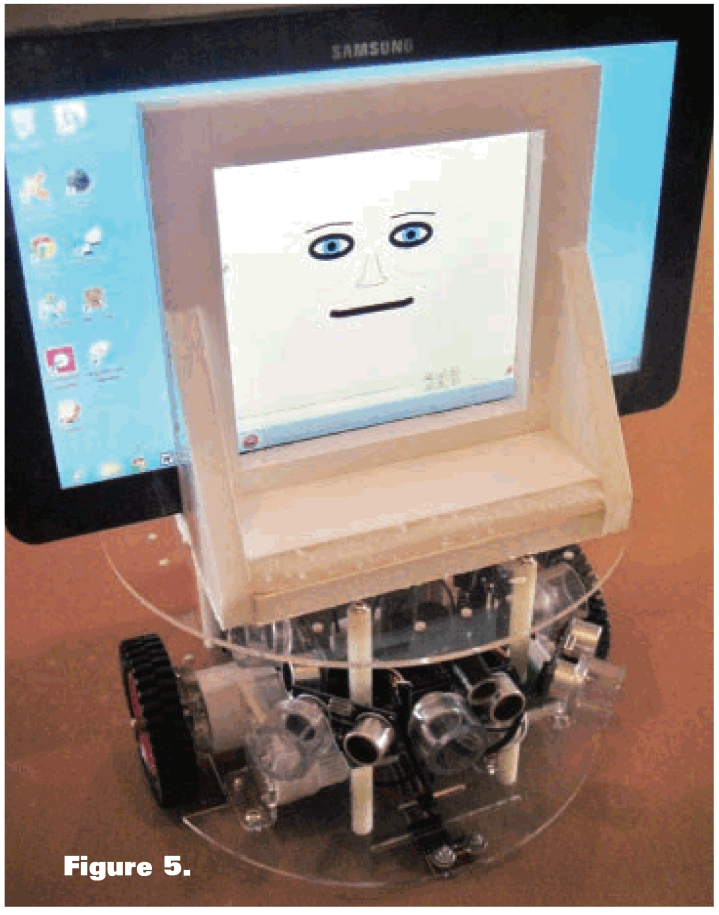


**Figure 5.**

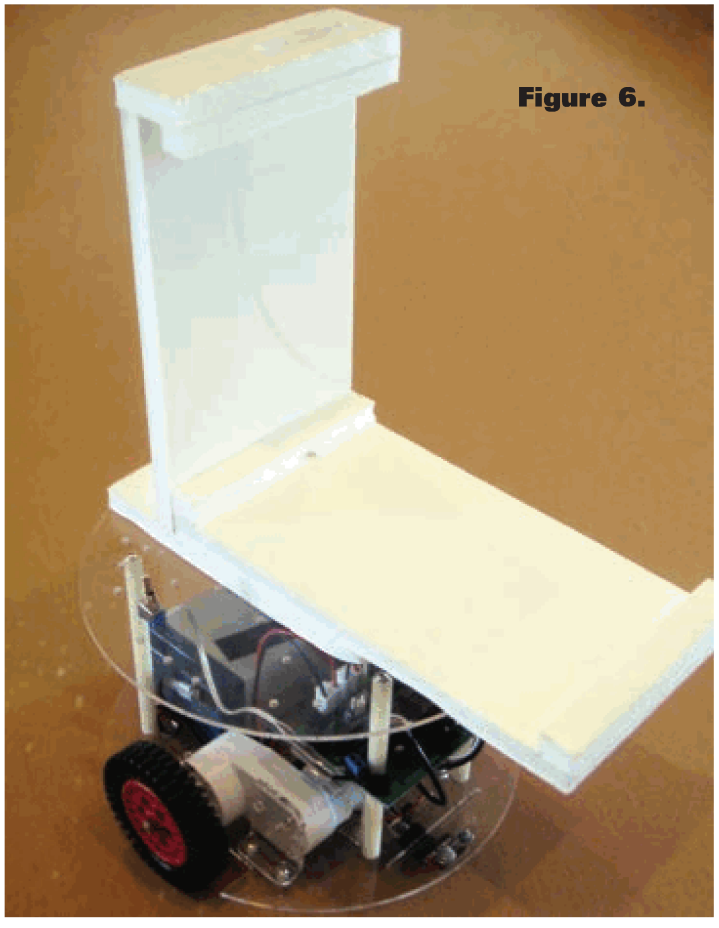

**Figure 6.**



Figure 7.

disconnecting the keyboard from the tablet.

## A Compass Example

The goal of our second project is for the robot to use the tablet's compass to first face a specified direction. Once there, the compass readings should be used to maintain the robot's heading as it moves forward until a nearby object is detected. The program in **Figure 8** shows how easily this can be accomplished.

This program performs two distinct actions. First, the robot must rotate to orient itself in the desired direction before moving forward. Then, as it moves forward, it should constantly turn slightly left or right based on a comparison of its current heading to the compass reading. Since our RB-9 robot has numerous other sensors, we will allow the robot to move forward until it detects an object blocking its path. Let's examine how the program works.

The *main* portion of the program is easy to follow because the function *AngleDifference* does all the hard work. For that reason, let's examine that function first. It is passed through three parameters. The first is the robot's current orientation angle, followed by the desired destination angle. The third parameter is the name of the variable where the actual difference between the two angles is stored.

Calculating the difference is more complicated than just subtracting the two angles — especially when the angles are on opposite sides of due north. If, for example, the robot is facing 350° with a desired destination of 5°, the difference of the two numbers will be 345 instead of the desired answer of 15. The function *AngleDifference* solves this problem by always returning the correct difference with its sign indicating which way to turn.

After initialization, the *main* portion of the program in **Figure 8** starts by establishing a destination angle. The *AngleDifference* function is then called to see how much the robot needs to rotate in order to face the destination.

In our case, the robot can be ordered to move to the desired orientation with a single *rTurn* command. This is true because our RB-9 has been set up and calibrated to make turns on its own by counting pulses from its integrated wheel encoders. If you are using a different robot, just create a subroutine that turns your robot in the proper direction until the desired heading is reached, making use of the internal compass if necessary.

Once the robot is pointing in the right direction, a *while-loop* moves the robot forward until an object is detected with the RB-9's front-facing ranging sensor. Inside the loop, the tablet's compass is constantly read and used to turn the robot back on course.

The *TurnStyle* parameter in the *rCommand* tells the RROS to use gentle turns (one wheel running slower than the other) as opposed to the default rotational behavior (where the two wheels run in opposite directions). Note: The RROS always uses the rotational style for turns with an argument greater than 1°.

Now that we have shown how to obtain data from the tablet sensors and use it to influence a robot's behavior, we are ready to explore a more complicated project.

Next month, our robot will use GPS readings and the compass routines developed this month to navigate to a general location where the tablet's integrated camera will be used to find an object of a specific color. **SV**

```
Main:
   call InitSensors(0,0,0,90) // set offsets
   call Orientation(Forw,Side,Rot,Heading)
   // display the entire array
   for i=0 to 6
      xyString 10,10+20*i,i; Sensors[i]
   next
   // display the processed readings
   xyString 10,160,"Forward Tilt    = ",Forw
   xyString 10,180,"Side Tilt       = ",Side
   xyString 10,200,"Rotational Tilt = ",Rot
   xyString 10,220,"Compass Heading = ",Heading
end

sub InitSensors(a,b,c,d)
  dim Sensors[28] //max available from utility
  for i=0 to 27
    Sensors[i]=""
  next
  // allow setting certain angles to zero
  dim Offsets[4]
  Offsets[0]=a
  Offsets[1]=b
  Offsets[2]=c
  Offsets[3]=d
return
```

```
sub Orientation(&t1,&t2,&t3,&h)
   // Request readings
   SetCBtext("tilt")
   filerename ("RBsTurn.txt","SensorsTurn.txt")
   // and wait for it to respond
   while !fileexists("RBsTurn.txt")
   wend
   // delay 10
   // get the data
   s=getcbtext()
   // and parse it
   mfromstring Sensors,s,","
   t1 = round(Sensors[1])+Offsets[0]
   t2 = round(Sensors[2])+Offsets[1]
   t3 = round(Sensors[3])+Offsets[2]
   h  = round(Sensors[5])+Offsets[3]
   // ensure heading within normal range
   if h>359 then h-=360
   if h<0 then h+=360
return
```

**Figure 8.**


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# Robot Wars: Roomba vs. Neato

***Everyone loves a rousing conversation about whose team, product, political party, or even robot vacuum cleaner is best. Usually in these conversations, both sides finally stop touting their opinions and quietly step to the side, holding to their particular views or convictions. However, manufacturers never stop trying to convince potential buyers of their product's worthiness. "We've been in business longer than our competitors." "Our product uses this unique technology that surpasses that of the other manufacturers." "We've sold more units than those other companies." All these and many more are typical of the hype used to convince customers that they are buying or have bought the best product.***

**Figure 1** shows the original iRobot Roomba introduced in 2002. Back then, there was only one company that made robot vacuum cleaners and there was only one model. I'm going to review two of the most prominent robot vacuum cleaners on the market, but more from a technical aspect.




**Figure 1. The original iRobot Roomba that started it all a dozen years ago.**

## Issues to Consider Regarding the Designs of a Robot Vacuum Cleaner

One might think that changing a basic upright vacuum cleaner's design by adding batteries and battery-powered motors for the wheels and impeller with some sort of simple navigation system might turn it into a robot vacuum cleaner. Not really. The fact that it must use batteries presents the greatest design hurdle.

A cheap 'standard' vacuum can use a relatively powerful AC motor and probably suck up just as much dust and dirt as a model twice as expensive. AC motors are comparatively inexpensive but basic vacuum cleaners are notoriously power-hungry beasts, drawing up to 10 amps at 120 volts. That is 1,200 watts — far more than any battery can supply. Therefore, inventive designers have to create systems for robot vacuums that can operate efficiently from a greatly diminished power source that will require regular replenishment at a charging base.

Improved impeller and cavity designs allow less powerful systems to closely match full-sized AC models. Simple suction alone does not pick up dirt and debris from a carpet. Sufficient air flow is required around each twisted strand of carpet to reach below the surface and cause the particles to rise to the top to join a larger flow of air into the vacuum cleaner's dust collector. One or more rotating brushes can assist in this task.

The required length of time over any part of a carpet determines the robot's speed. Faster means less time to clean an area but hastens the job's completion, whereas a slower movement means better cleaning at the expense of a longer overall process. A designer must be cognizant that a robot vacuum cleaner will not have a human behind it, holding onto a handle and directing it to all the places that need cleaning. A robot vacuum must not ding walls, suck up drapes, cats, wires, or rug fringes, or dive down the stairs. It must cover all carpet areas only once — something that a human can easily see by marks on the carpet.

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Wall and floor sensors matched with a microcontroller and sensible navigation algorithms allow the robot vacuum cleaner to intelligently roam about a carpeted floor as it cleaned. An edge detector sensor prevents the robot cleaner from diving to its death from the top of a staircase. Companies have added virtual walls, lighthouses, or magnetic strips placed on the floor to help confine cleaning to a single location. 'Back to base' software and sensors allow the robot to return to its charging station when the batteries are low or the cleaning task is completed.



**Figure 2. Mint Northstar Navigation Cube.**

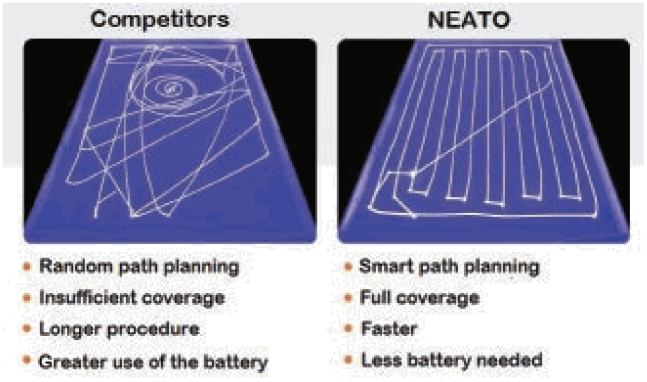



**Figure 3. Navigation path comparison for the Neato with SLAM and laser mapping.**

## iRobot Roomba

The two manufacturers of robot vacuum cleaners on the market I will discuss are the Roomba and the Neato, with a short mention of the Evolution Robotics Mint Northstar system.

iRobot has been in business since 1990 and was founded by MIT professor, Rodney Brooks and two of his previous students — Colin Angle and Helen Greiner. They worked together in MIT's Artificial Intelligence Lab. Angle is the only one of the three still at iRobot as the other two have left to form their own companies.

iRobot had a bit over 500 employees in 2012 (having peaked at 657 in 2010) and had sold over eight million Roombas by the end of that same year. Their military PackBot was the first truly successful product prior to their introducing the Roomba line of home robots in 2002. The home robot division has since launched the Scooba floor washing robot, the Looj gutter-cleaning robot, and the Verro pool-cleaning robot. As iRobot has numerous types of robots, I'll only list the six Roomba vacuum-cleaning models that range from $349.99 to $699.99. The three Scooba floor-washing models range from $278.99 to $499.99, and the two Braava floor-mopping robots (was the Evolution Robotics Mint) go for $199.99 or $299.

In late 2012, iRobot acquired Evolution Robotics for $74 million — the makers of the Mint hardwood floor-mopping robot that uses the Northstar navigation platform and SLAM (Simultaneous Localization And Mapping) navigation for room mapping and auto return to its charging station. This technique uses a small IR projector placed on a nearby table and an onboard camera to determine the robot's position on the floor.

The small IR cube shown in **Figure 2** is positioned in the center of a room and projects two infrared spots on the ceiling; an onboard processor tracks those spots. An ARM7 microcontroller computes and creates a map to show the Mint's location. As with all robot floor cleaners, the Mint uses a gyro and wheel encoders to assist in navigation. The projected spots can be in just one room, and the Mint can then navigate to all the other rooms needing cleaning. iRobot has rebranded the Mint technology as the Braava which makes unique use of the Northstar navigation system.

## Neato Robotics

Neato Robotics is a small Silicon Valley startup that began business in late 2009. In 2010, they debuted their first product: the XV-11 robotic vacuum cleaner. It was priced at $399 and was released for sale in February of that year after months of media hype and Internet buzz about an entirely new type of robot vacuum cleaner. The company has around 50 employees, with all of the engineering and design work done in their main offices in Newark, CA. Neato CEO is Giacomo Marini; the CFO is Holly Anderson; the VP of Engineering is Mike Perkinseato; and Nancy Nunziati is VP of Marketing.

The Neato series of robot vacuum cleaners is contract manufactured in China, as is the Roomba and most other similar products. The first reviews were very positive, mainly because of the unique SLAM navigation system that allowed a more precise sweeping pattern on room carpets as depicted in **Figure 3**. The Neato's LIDAR module will be discussed later in this article.

The Neato XV-11 as well as the XV-12 are still sold at $379.99, as are the XV Signature for $399.99, the XV-21 for pet owners at $429.99, and the XV Signature Pro for $449.99.

Here's how Neato describes their XV Signature Pro professional grade cleaning: *"Advanced laser guided navigation and powerful suction ensures your Neato goes automatically from room to room, cleaning close to edges, in corners, and carefully around furniture. It*

*returns to the charge base and resumes where it left off. It offers easy scheduling of daily cleaning or a button for instant cleaning. The versatile brush system offers superior pick-up of pet hair, dander, and fiber on all floor types. The special filters retain more than three times the amount of fine dust particles as standard filters, which is perfect for removing allergens from the home."*



**Figure 4. iRobot Roomba 560.**

## Performance Evaluations

I've had my Roomba 560 (shown in **Figure 4**) for five years now. It was given to me by Helen Greiner (Chairman of the Board of iRobot at the time) to test and evaluate. This was just before she left the company in October 2008 to start her own company, CyPhy Works. Helen has degrees in Mechanical Engineering and Computer Science from MIT, and she was a most interesting technical conversationalist. We talked at length about military robotics, her main interest at iRobot, and robotics to assist the elderly in independent living — a particular interest of mine. With her technical and business acumen, I know her magic touch will continue to help her own company succeed.



**Figure 5. Two different Roomba brushes with hair buildup.**

## Roomba 560 Testing

Back in the day, almost immediately, I began to have trouble with the Roomba 560, so I contacted Helen about it. She put me in touch with several of her technical people to discuss the problems. The Roomba would operate quite fine for a half hour or so, and then would stop and tell me "Please clean Roomba's brushes." I checked them and found only a tiny bit of dirty fuzz, pulled out some hair near the bearings, and returned it to cleaning. The "clean me" message came again too quickly. Hmmm. What was making the machine think the brushes weren't clean? Something must be causing a higher current draw on the motor.

I pulled off the yellow plastic-capped bronze bushings (**Figure 5**) and saw two types of hair bound on the brushes. You can see the bearing containing a bronze bushing on the right of the bristled brush and the left of the rubber brush. The fluffy hair was easily removed with a pair of tweezers and an XActo™ knife. However, there remained a tiny cone of hair tightly fused on the steel shaft. This cone had been burnished by the bronze bushing's friction and melted into a solid mass.

It appeared that this cone was slowly building up like frozen ice and was pushing the bushing up the brush shaft that was then shoved into the gearbox, damaging it. Hair was the culprit, and just a tiny amount! Other Roomba owners posted on the Internet that hair often entered into the gearbox through cracks caused by distortion of the case, jamming the gear train.

I placed two digital voltmeters on the battery supply: one in series for a current measurement and one in parallel to read the battery voltage. After carving away the 'hair cone,' I started up the Roomba. After a half hour, sure enough, the current started to rise, the voltage dropped, and, lo and behold, Roomba soon cried out again to "clean my brushes." A few slices with my XActo knife and it was working again.

I called iRobot and attempted to get in touch with engineering personnel as I had heard they had many returns due to damaged gearboxes. It was not until last year that I finally saw they had changed the bearings and end caps to remedy this problem. **Figure 6** shows the new green brush end rim that encloses the problematic bearing assembly. I never saw suggestions printed in their literature or on their website about the 'hair cone' buildup, but the new brush end design seemed to have eliminated this issue.

Despite the hair problem and shorter battery life than I expected, I was and still am impressed with the Roomba 560. Using an entirely different approach and algorithms for the cleaning process, the 560 does a good job cleaning my carpets. Many reviewers have tested robot vacuum cleaners by sprinkling Cheerios, sawdust, and even flour on hardwood and carpeted floors to test how fast and thoroughly the debris is removed. Normally, these types of spills are picked up with a broom and dustpan.

The robot vacuum cleaner is at its best when picking up *random* debris. I have found that Roomba does a good job picking up the typical debris like grass pieces, dirt, and sand particles (and that 'fluff' that looks like dryer

lint). It does manage to toss about particles as large as cat litter, however.

It is the carpets that I am most concerned with, and the Roomba's random pattern eventually covers the whole floor of a room – except for tiny corner 'triangles' of missed carpet areas. It moves a bit faster than the Neato and bangs into walls a bit more than I'd like – especially chair and table legs that are difficult for the sensors to detect.

Roomba is quieter than Neato. **Figure 7** shows a particular problem with a rocking chair's rockers that both robots found to be difficult. **Figure 8** shows the two 'lighthouses' set up to restrict the Roomba to a single area. (Keep in mind here that I am testing a five year old Roomba against a new Neato, although I have also tested with a newer Roomba 770 and I personally saw little difference between that one and my old 560.)

## Neato XV Signature Pro Cleans Up

The new Neato XV Signature Pro shown in **Figure 9** is not as pricey as the top-end Roombas and is a bit heavier than my 560, but is about the same as the 770. Both use 14.4 NiMH battery power, but Neato's batteries divide that into two 7.2 volt packs (**Figure 10**) that end up costing more for the pair of replacements than Roomba's single battery (**Figure 11**). Online replacement battery costs for both robots vary greatly as does the mAh capacity (from 3,000 to 3,500). The battery life for my Neato demo model was quite a bit lower than I expected at 27 minutes.

Some reviewers have commented that the Neato is a bit 'plain Jane' in that it doesn't have all the bells and whistles with its controls like the top line Roombas. I personally do not feel that way. I found that the five buttons, the LCD display, and the audible sounds gave me all the information that I needed to program and operate the XV Signature Pro to perform all the cleaning tasks that I desired (as did my wife).



**Figure 6. Improved brush bearing protection from hair buildup with a steel shaft.**



**Figure 8. Lighthouses set boundaries for the Roomba's cleaning space.**

It smoothly transitioned from my carpeted areas to hardwood floors with ease, adjusting sweeping height in the process. I really don't like having the magnetic strips laid down on the floor to constrict the Neato to a specific area, but they do work. Maybe robot vacuum manufacturers can arrive at a better solution other than these strips or IR lighthouses. Maybe some sort of IR-activated invisible line drawn on the floor with a special ink would work.

I also noticed the Neato didn't seem to knock cat litter particles across the floor as the Roomba did, but actually swept them up. It is a bit noisier than the Roomba, but I like the sound. The high-suction fan sounds cool as it spools up like a jet fighter, ready for a catapult launch.

The rotating LIDAR, brush motor, and wheel motors all add their



**Figure 7. My Roomba got hung up on rocking chair rockers.**



**Figure 9. Neato XV Signature Pro.**

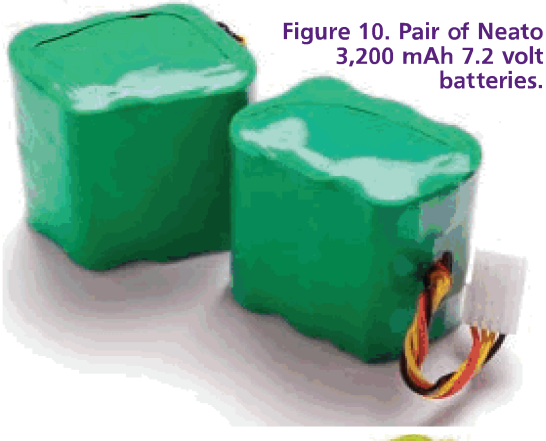


**Figure 10. Pair of Neato 3,200 mAh 7.2 volt batteries.**



**Figure 11. iRobot Roomba 3,000 mAh 14.4 volt battery.**

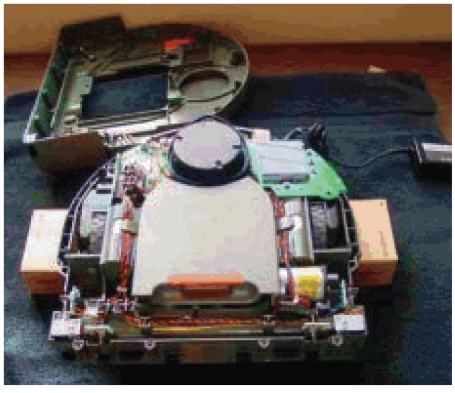


Figure 12. Neato peeled open to reveal its LIDAR module.



Figure 13. Top of the Neato LIDAR module.

sounds, but I didn't mind them. I still find both robot vacuum cleaners much quieter than either of my upright vacuums.

The Neato's square front seemed to clean corners better than the Roomba, but overall the final cleaning results were not really that different.

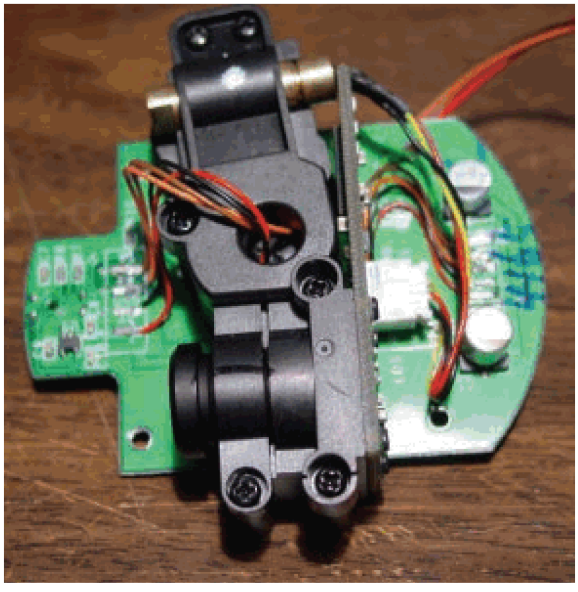


Figure 14. Camera and laser mounted in front of a LIDAR circuit board. *Courtesy of Random Workshop.*

## Neato Technology — the LIDAR

The rotating laser emitter/receiver LIDAR module can be seen at the far end of the Neato chassis in **Figure 12.** This affordable LIDAR — shown opened up to expose the components in **Figure 13** — has created a lot of interest among robot builders, and it is the center of some hacker controversy. The acronym LIDAR is derived from the acronym RADAR (RAdio Detection And Ranging) but substitutes LIght for RAdio. The 360 degree scanning LIDAR on the Neato series has a one degree accuracy and a 10 Hz refresh rate, measuring distance data out to six meters (almost 20 feet).

It should be noted that the LIDAR rotates in a single plane and can only detect objects positioned within that plane at about 3-1/2" above the floor. Software algorithms allow the robot to map the room to assure thorough coverage (as shown back in **Figure 2**) and to return to its charging base when needed.

As most robot builders have heard, the robotics community and many hackers have salivated at the Neato series of robot vacuum cleaners since the very first one hit store shelves. Not only have people removed the module from both new and used Neato's, but they've also extracted the different components to use in similar applications.

**Figure 15** shows the LIDAR board stuck in Play-Doh as a means of keeping it stable while the guys at Random Workshop measure the laser output pulses. I personally like the vacuum cleaner enough to not rip it apart to try to use the LIDAR module in other applications, but there are

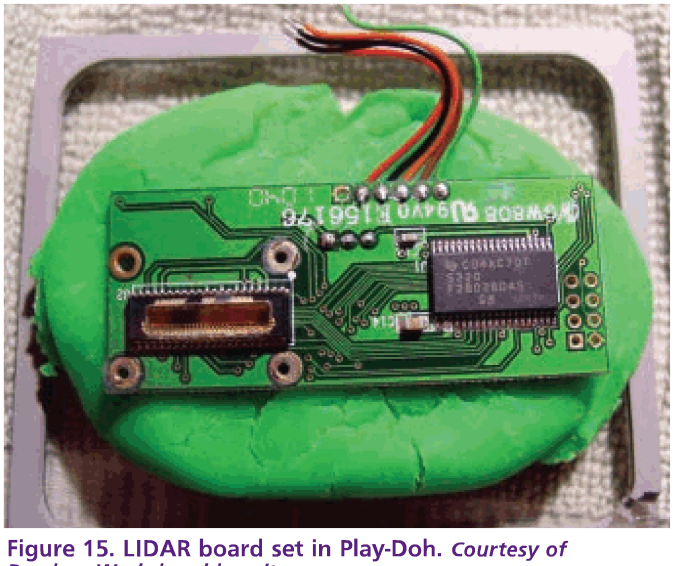


Figure 15. LIDAR board set in Play-Doh. *Courtesy of Random Workshop blog site.*

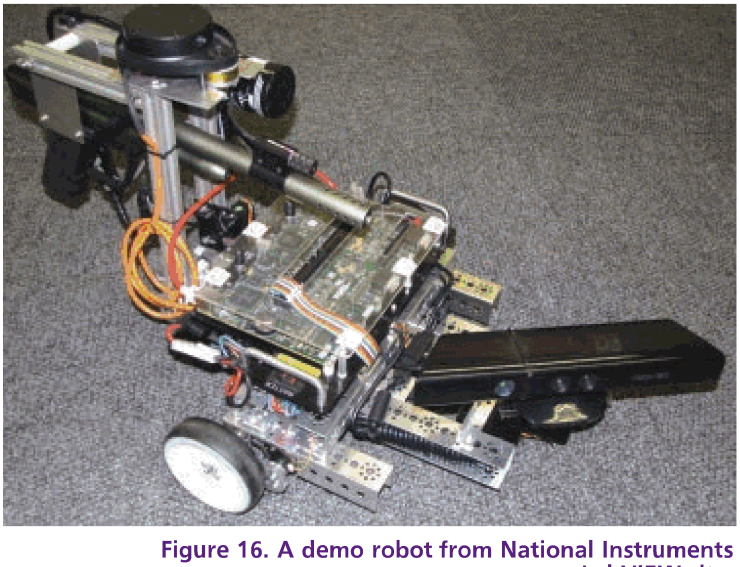


Figure 16. A demo robot from National Instruments LabVIEW site.

older ones available in thrift stores and even on eBay.

**Figure 16** shows a demonstration robot that uses National Instruments' LabVIEW Robotics Starter Kit 2.0 and hints from **LabVIEWHacker.com**, plus structural materials from Actobotics™ and others. They used a Microsoft Kinect for basic image detection but needed to add a LIDAR module from a Neato vacuum cleaner to create a better overall navigation system for the autonomous vehicle.

## Which is the Best Robot Vacuum Cleaner?

In a way, that is like asking who has the best NFL football team. Everyone has their own opinions about anything in life, and there are many who would refuse to change their mind despite overwhelming evidence pertaining to some other choice. The short time that I had with the $699.99 iRobot Roomba 790 showed me that this top-of-the-line machine was truly first class and did a great job of cleaning both carpets and hardwood floors. However, I do not believe that it out-cleaned the Neato XV Signature Pro.

The Roomba 790 was certainly a better machine than my five year old 560 (that is no longer sold), but that was to be expected with its troublesome brush ends and age. Hair on the floor was not a problem for the Neato or the new Roomba. The Neato only slightly bumped into furniture but the Roomba would occasionally slam into a chair leg that it did not see. Programming all three robot vacuum cleaners was different, and none stuck out as bad or great. Neato's way to return to its charging base by *remembering* the base's location seemed better than Roomba's *search* for the base.

I have yet to get hands-on experience with iRobot's just-released 800 series, but it appears they've completely eliminated bristled brushes and replaced them with counter-rotating rubber bladed 'AeroForce Extractors' that mesh together. It's been reported these also assist in the vacuum's airflow with an apparent 5x increase in suction. Coupled with their new XLife battery, this smaller 'brush system' allows for an increased dirt bin size.

Taking into consideration the costs of the Neato XV Signature Pro robot vacuum vs. the iRobot Roomba 790, the SLAM navigation vs. the random sweeping algorithms, and the ability to update the Neato's software, as you may have guessed I would choose the Neato over the new top-of-the-line Roomba. I tried to not be influenced by the many reviews that I found online, and stuck to my own testing methods. Both machines gave me some frustrating battery problems, as I had to change out the Roomba's battery twice (in five years) and the Neato's set of batteries once (almost immediately).

All robot vacuum cleaners do have one feature that can be considered both very good and very bad at times: They are autonomous. Of course, the autonomy allows a user to program the machine to clean while they are away. Unfortunately, this autonomy will not help the vacuum when it gets stuck on something.

## Final Thoughts

Both robot vacuums that I tested work very well, but they need more (and different!) attention than a traditional upright. They require special border markers to prevent them from wandering into places where they should not be. They also hold less debris, so the dustbin has to be emptied more often and the brushes cleaned on a regular basis. I recommend that rather than hacking your Neato or Roomba, you buy an iRobot Create base for $129, or buy a used or older Neato and hack it for the LIDAR module.

Either way, you'll really clean up with a very useable robot for experimentation. SV



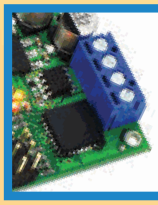

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HiTec .....2, 80
Karlsson Robotics .....80
Maxbotix .....80
OceanServer Technology .....9
Oscium .....19
PanaVise .....10
PCB Pool .....20, 80
Pololu Robotics & Electronics ...3, 80
RobotShop, Inc .....80, 81
SDP/SI .....25
Servo City/Robot Zone .....80, 83
Sherline Products .....10
Solutions Cubed .....29
Sphero .....11, 80
The Robot Marketplace .....38
Tormach .....7
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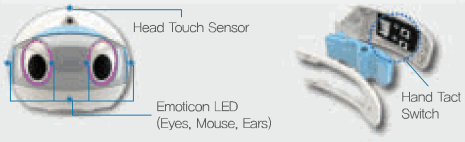


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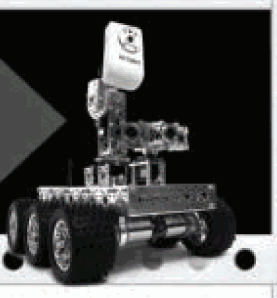
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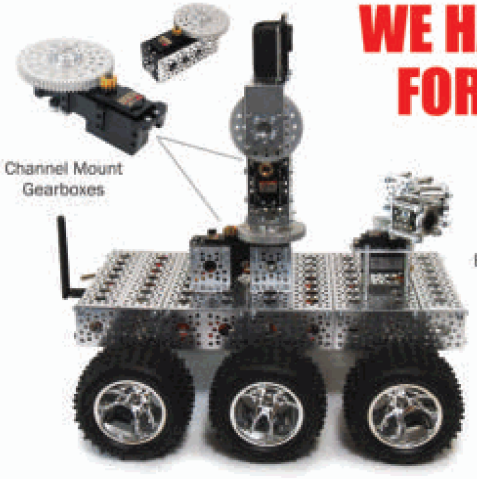
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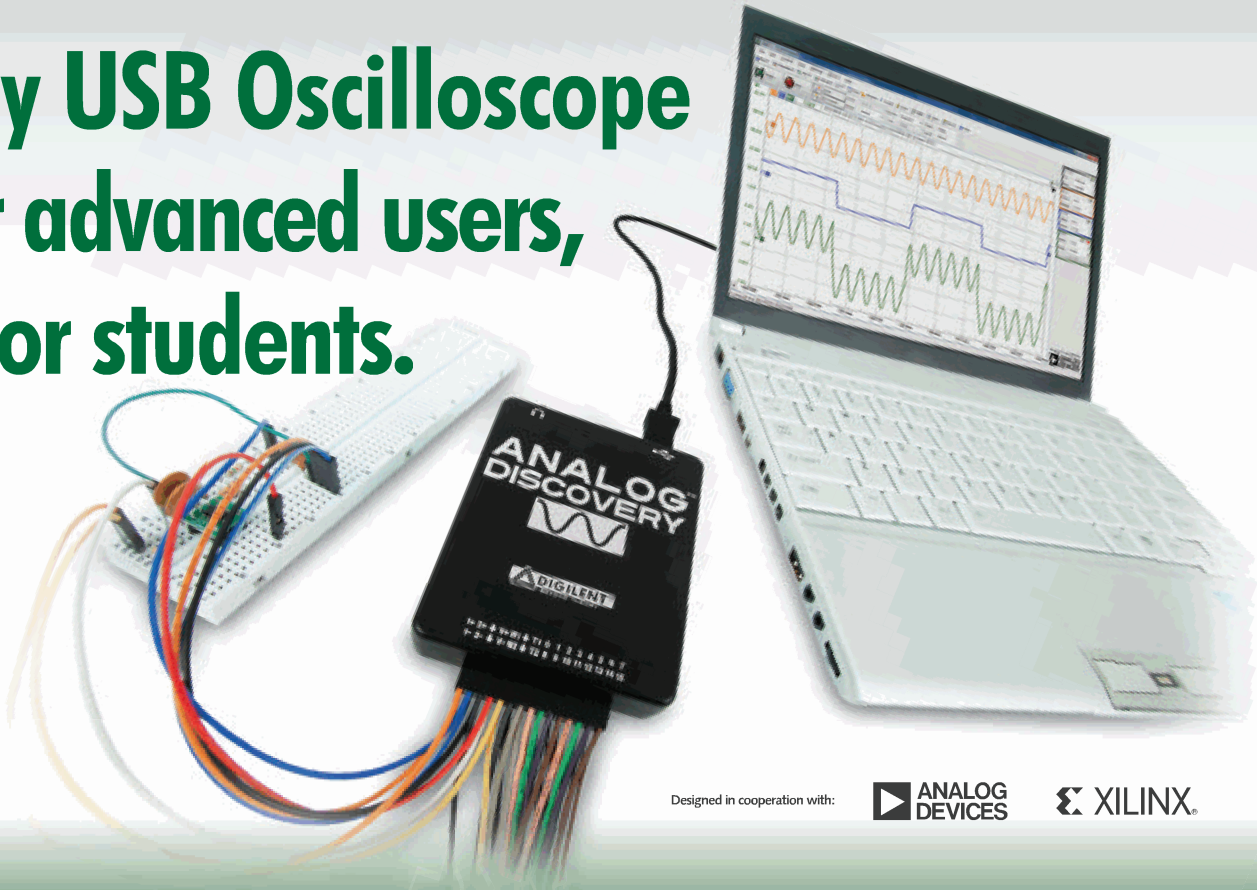
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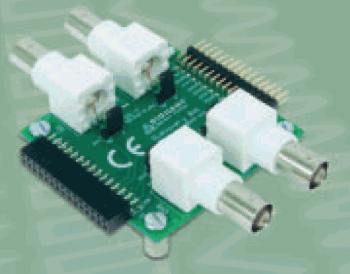
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