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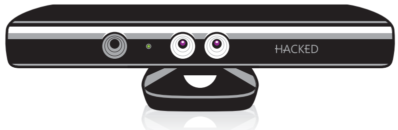
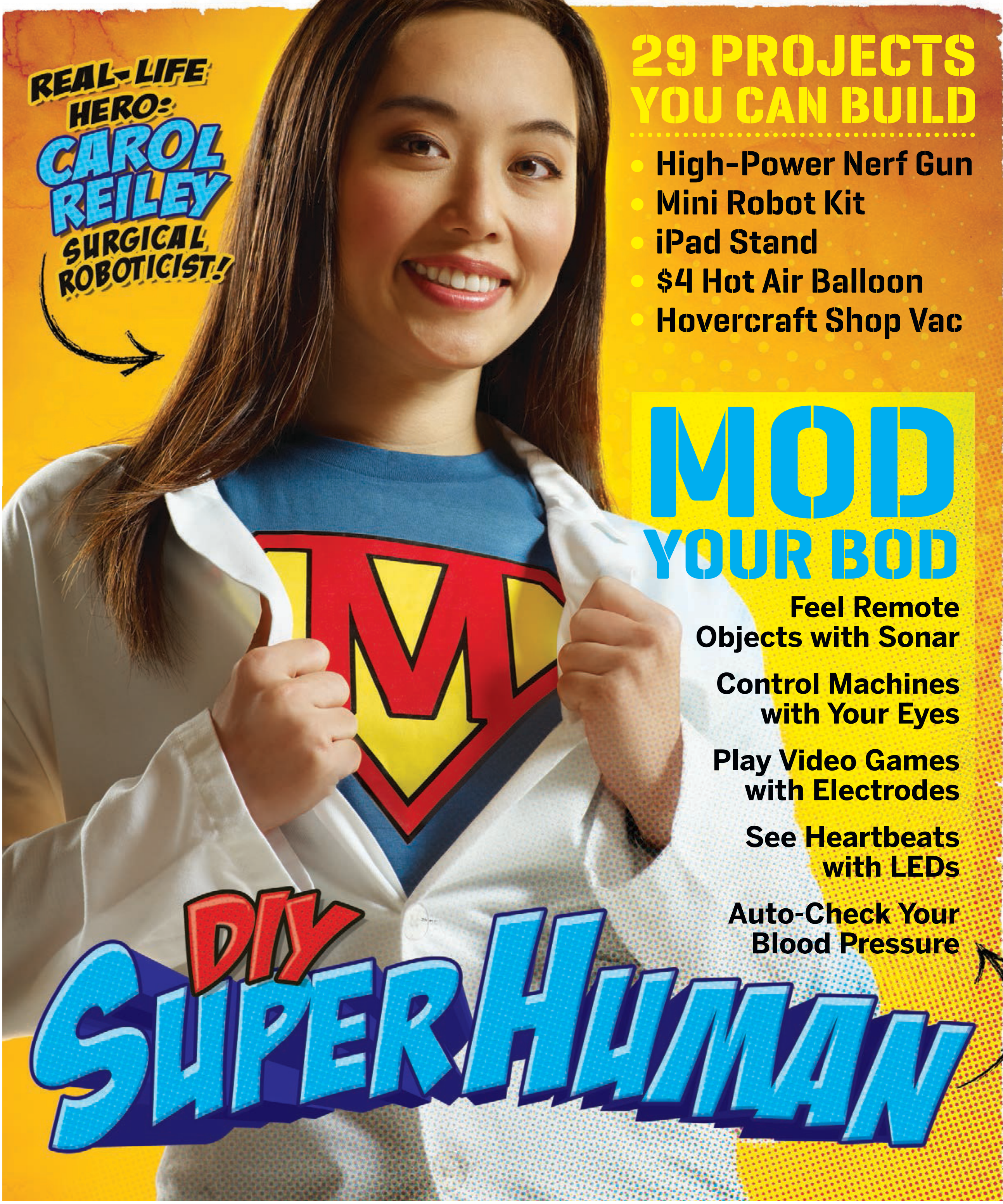


Hack the Kinect | 124



REAL-LIFE HERO: CAROL REILEY SURGICAL ROBOTICIST!

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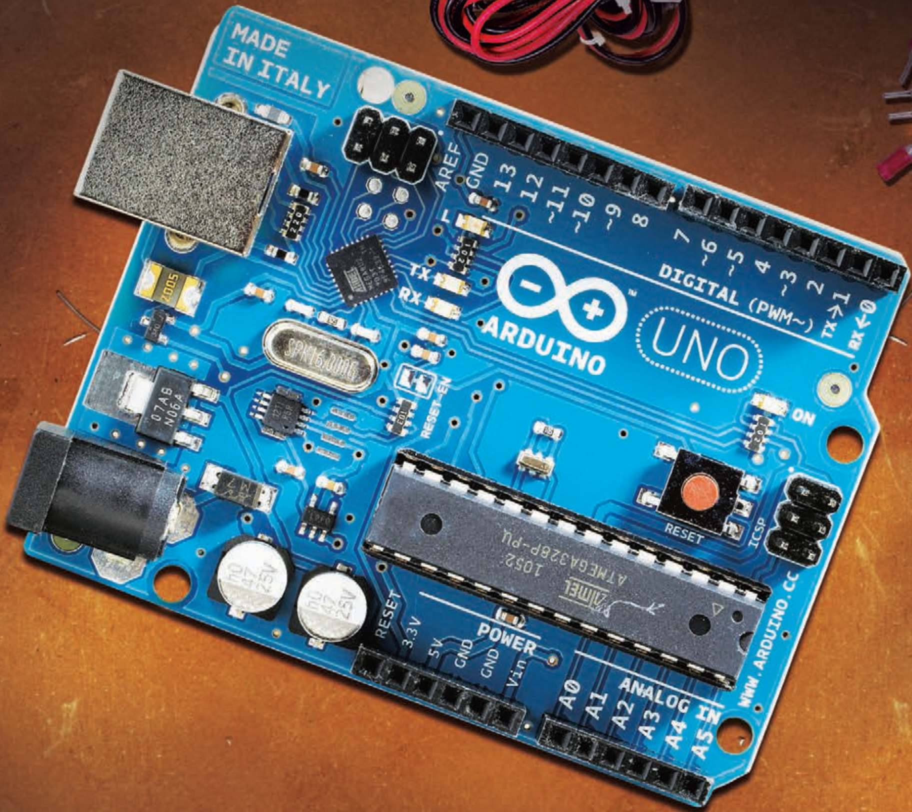
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Make: Volume 29

DIY SuperHuman

Columns

CAROL REILEY: "I'm interested in using robots to train the next generation of robots." Photography by Garry McLeod. Styling by Yvette Swallow. Art direction by Jason Babler.

ELECTRODE GUITAR: Build a system that lets you play video games without pushing buttons.

PRESSURE'S ON: Make this chargeable, portable, blood pressure monitor on the cheap.

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SURVIVAL PACK

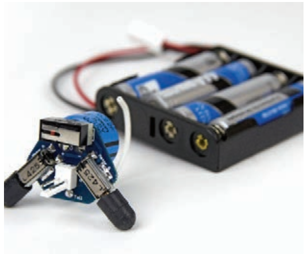
[MSTIN2] $20

Mintronics Survival Pack contains over 60 useful components for making, hacking, and modifying electronic circuits and repairs on the go.

MINTDUINO

[MSTIN3] $25

The MintDuino allows you to build your very own ATmega-based microcontroller from scratch — a great way to learn the fundamentals.

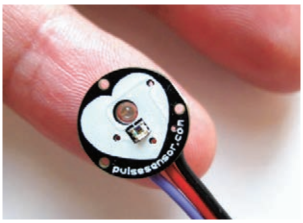


SUPERCAP RACER

[MSTIN4] $25

Perfect for parties and easily customizable, the Mintronics Supercap Racer is a great way to hone your soldering skills and battle it out with friends.

MAKE Volume 29



PULSE SENSOR

[MKRE1] $20

Capture your heartbeat! Use it in lie detectors, relaxation aids, fitness training, games, or any project that might require a “human” element.

MAKE Volume 23

USELESS MACHINE

[MKSB023] $25

What does this machine do? It turns itself off. You turn it on again, it turns itself off again. Great for hours of useless fun for the whole family.

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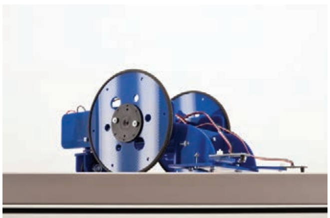

TINY WANDERER

[MSTW01] $179

An easy-to-make tabletop robot that uses proximity sensors to keep from falling off the edge. Learn how to build one on page 88!

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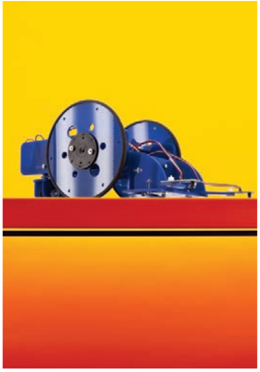
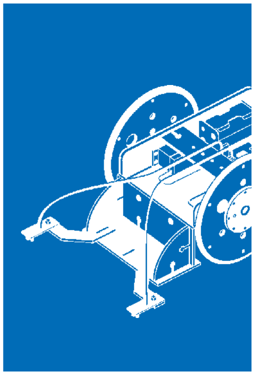
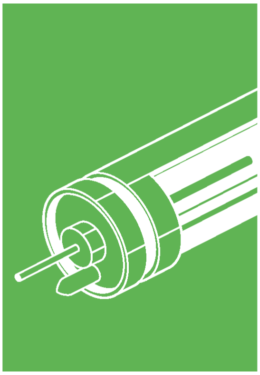
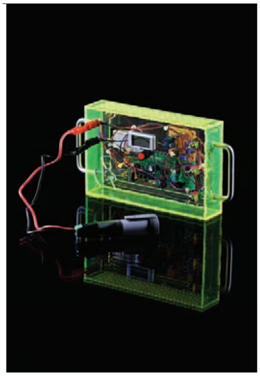
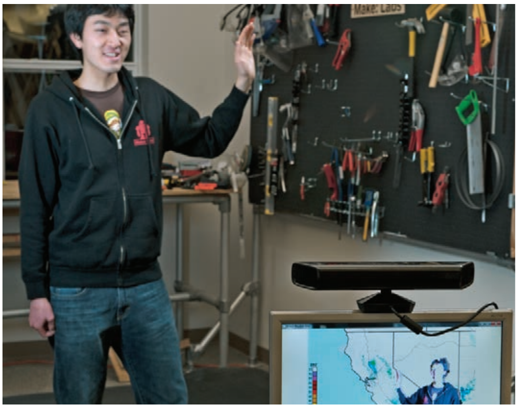
Make: Projects







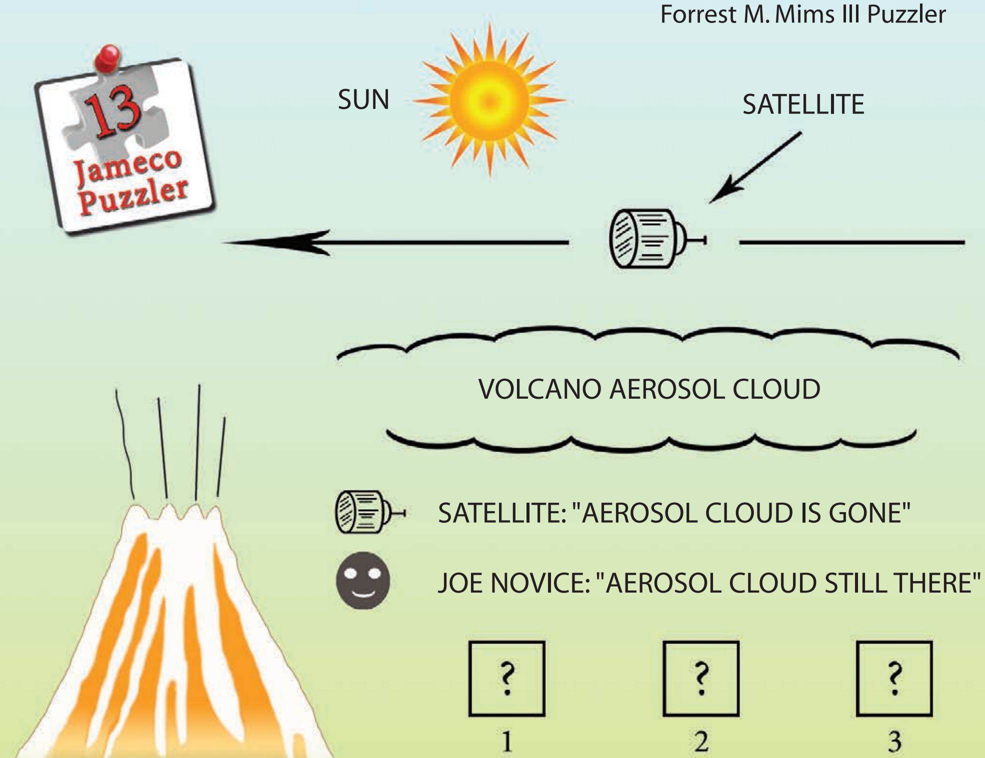




Can You Solve This?

Forrest M. Mims III Puzzler

13 Jameco Puzzler



Can you describe any of the three methods Joe used to detect the aerosol?

Satellites provide global coverage of clouds, water vapor, dust, smoke and the ozone layer. The colorful images provided by the data from these satellites looks very impressive. But satellite instruments don't always stay calibrated and problems can occur when satellite orbits drift. Amateur scientist, Joe Novice learned about this when he heard a satellite scientist say that the global aerosol cloud formed by the eruption of a giant volcano had dissipated much sooner than expected. Joe suspected the satellite was simply wrong, but he was not a satellite scientist. How did he use some everyday items and several electronic components to prove he was right?

What's your solution? See if you are correct at www.Jameco.com/unknown13 where you will find all three of Joe's solutions.

Make: Volume 29

Maker

READ ME: Always check the URL associated with a project before you get started. There may be important updates or corrections.

KYLE MACHULIS: A forward-thinking reverse engineer who focuses on opening the closed.

DIY

ARDUINO MASH: Microcontrolled moonshine from a prohibition-era copper still.

> **"So many dreams at first seem impossible. And then they seem improbable. And then when we summon the will, they soon become inevitable."**
> ***—Christopher Reeve***

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CONTRIBUTORS

"I still can't believe people pay me money to draw," says **Damien Scogin** (with over 15 illustrations in this issue), even after eight years of steady illustration for the magazine world. With grandparents who taught and encouraged drawing at a very early age, and a photographer father, Damien has been thinking and working visually as long as he can remember. After a recent move to the East Coast, he has rekindled an appreciation for a nice Eastern hardwood forest and the confounding intelligence of the average Catskill trout. He currently lives in the northern fringes of New York City with his lovely wife and fat purple cat.

Simon Jansen (*Better Nerf Gun*) is "a geek, a tinkerer, a scientist, a perfectionist, an inventor (of nothing particularly useful, it must be said), an Anglophile, a train-spotter, and still very much in touch with [his] inner child." His current projects include fixing up a 1936 Austin 7, a talking John Steed Thunderbird-style marionette, and "a model railway, 1930s British-themed, that will go into a dining table." He works in the Auckland, New Zealand, office of a U.S. software company, likes making things just for the sake of the making, and just discovered thread files (metal files for cleaning up damaged bolt threads).

Jesse Brumberger (*$4 Hot Air Balloon*) has worked as a mechanical engineer for about 25 years in all sorts of industries, from copiers to aerospace. He's been making and building things since he first got his hands on a Meccano set, around age 5. With more skills, money, and tools later in life, he got into amateur machining, making everything from miniature running engines to cool toys for his son, who Jesse has encouraged into making and building things as well. He has also finally gotten in some pilot training; one of these days maybe he'll take on that ultimate fantasy of the homebuilt airplane.

Rob Nance (*Geiger Counter* and *Tiny Wanderer* illustrations) is a human being, and he loves being a human being most when eating candy stars and frosting from what humans call "cake." He has contributed chromosomes to two darling human babies, Sophia Marie (3.5 Earth years old) and Mei Zola (2.333 Earth years old). He is married; she is also a human. He enjoys eating human food and is also not allergic to sunlight. When not gathering samples of human fluids, he is sketching in his logbook, mostly pictures of flowers, rainbows, puppies, and destruction rained down from the heavens (he particularly enjoys drawing Frank Gehry's work in flames). End communication.

Alex Russell and **Garrick Orchard** (*Blood Pressure Monitor*) are currently Ph.D. candidates in the Computational Sensory-Motor Systems Laboratory at Johns Hopkins University. They received their B.Sc. degrees in electrical engineering in mechatronics from the University of Cape Town, Rondebosch, South Africa, in 2006, and their M.S.E. degrees in electrical engineering from Johns Hopkins University in 2009. Alex enjoys warm weather, sailing, and spiking neurons and networks. Garrick enjoys photography, traveling, and mixed-signal, very large scale integration (VLSI) design coupled with intelligent, compact, low-power sensors for mobile robotics. They are both coffee addicts.

John Iovine (*Geiger Counter*) is a science experimenter and writer. He has written books and articles on a variety of topics in science and electronics, such as photography, microcontrollers, virtual reality, and neural networks. John's book publishers range from McGraw-Hill to Focal Press, and he has been featured in magazines ranging from MAKE (of course!) to *Scientific American*. John is the owner-operator of Images Scientific Instruments, Inc., a small science and electronics manufacturing company. He resides in Staten Island, N.Y., with his wife and two children, their dog, Chansey, and cat, Squeaks.


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WELCOME

By Dale Dougherty

Experiment On Yourself

CHARLES DALZIEL, A UC BERKELEY professor who studied electricity's effect on animals and humans and reputedly did a fair amount of testing on himself, realized that most accidental electrocutions happened because of a ground fault in home electrical circuits. So he set out to develop the Ground Fault Circuit Interrupter (GFCI), which monitors the current and instantly trips it when detecting an imbalance of as little as 5mA, a level his tests determined to be harmless. Dalziel patented the device in 1965, and the GFCI was later incorporated into the National Electrical Code, requiring GFCI outlets in all homes. Within 25 years, his invention was responsible for reducing by half the number of such accidental deaths in the U.S.

I won't look at a GFCI again without imagining Prof. Dalziel administering a small shock to himself and then writing a note.

History is full of quirky tales of scientists who were first in line to try their own experiments. So are comic books, although super villains are more likely than superheroes to be self-experimenters. When the subject of scientific research becomes the researcher herself, that's self-experimentation, a gray area in academic science that continues to find strong interest among amateurs.

David Ewing Duncan, author of *Experimental Man*, set out to be the subject of every test a human can take. He was determined to uncover the secrets of his DNA and identify all the toxins that call his body home. One morning, he tested the mercury level in his blood, and then ate local fish for lunch and dinner. The next day, he tested again and the results showed a threefold increase. I thought of Duncan when I saw a picture of a chef using a radiation detector in a fish market following the Fukushima incident in Japan.

Anne Wright had a dream job working on the Mars Rover until she became too sick to work. Doctors were unable to figure out what ailed her, so she began monitoring her body and the environment where she lived. She got to the bottom of her allergies by systematically photographing and detailing everything she consumed. With new sources of data, she started debugging her own system.

Anne now runs an open source project called BodyTrack (bodytrack.org) to promote the development of new tools for aggregating data. One Body-Track study discovered that, after frying food in the kitchen, the air in the house contains high levels of particulates for hours after the meal is over. Turns out, you breathe what you cook.

Self-trackers were first applauded by Kevin Kelly and Gary Wolf and organized under the name Quantified Self (QS). A combination of QS apps and gadgets are used to generate data to track performance, say for fitness, health, or mental acuity. (Is your memory better in the morning or evening? You can set up an experiment and test yourself.) Most surprising is how seriously the self-trackers take themselves and their results. They are the cutting edge of self-improvement, and the health industry is watching with amazement.

If devices provide a constant feedback loop, are we more likely to change harmful behaviors or realize new strengths?

In this biotech issue of Make, we feature projects that help you explore the promise of self-experimentation. It's like getting new eyes or ears or arms. This is about as personal as technology can get. It's like *The Six Million Dollar Man*, but on a DIY budget. The results could shock you.

Dale Dougherty is founder and publisher of MAKE.

READER INPUT

From Makers Like You

Robot Girls, DIY View-Master, and Arduino Hype

My daughters and I enjoy MAKE. It always inspires us. Over the last year or so, Camille (11) and Genevieve (9) and I have been hard at work building robots. We've built over ten so far. The girls are involved in the designing, naming, soldering, electronics, metal fabrication, programming, and testing of the robots, with Dad guiding the way.

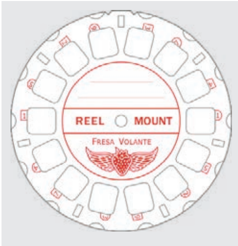
Our two most recent robots are a Mars Rover, complete with NASA-style rocker-bogie suspension system, and a mechatronic tank with Mecanum wheels (see videos of both at beatty-robotics.com). We've also built quadrotors, crawlers, and others. I thought you might like seeing some of our creations.

—*Robert Beatty, Asheville, N.C.*

I was thrilled to see Bob Knetzger's article "Mastering 3D Views" in MAKE Volume 28. I'm an avid user of the View-Master Personal Stereo Camera system to make my own View-Master reels. However, I was crushed when I read that "the empty View-Master reels aren't made anymore."

It *is* possible to get empty VM reels — I make them! I got frustrated at the expense of buying old reels on eBay, so in 2005 I started shipping new reels under my label Fresa Volante (fresavolante.com).

—*Nick Merz, San Francisco*



View-Master: my favorite subject. Readers might want to know that you can get aftermarket reel blanks from Fresa Volante and old blank reel stock on eBay. View-Master's blank reel machine operated until 2000, and in its last year they saw a dramatic increase in demand, since word got out they were mothballing the machine. People stocked up and are still selling their excess.

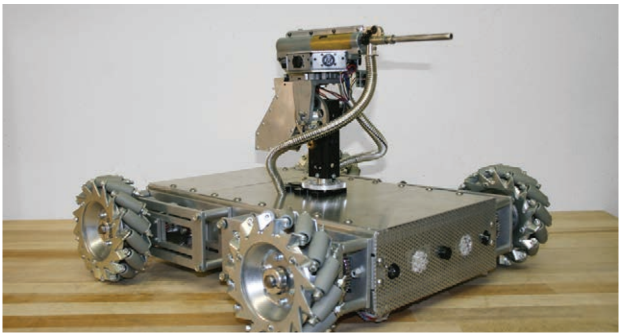
At my website, vmresource.com, you can find a template for formatting digital images for the original blank, instructions for modifying the cameras for electronic flash, and other tips and tricks (plus a PDF of the manual).

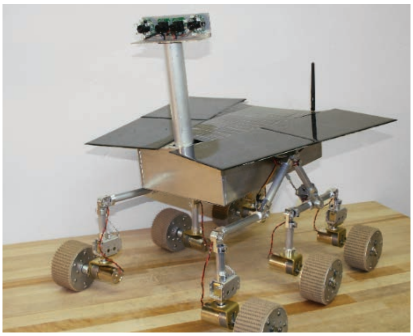
Also: although William Gruber was a genius and developed the View-Master format, most of the camera design and the Personal Stereo system were developed by two other geniuses named Gordon Smith and Karl Kurtz.

—*Eddie Bowers, Dallas*

Thanks for the awesome projects. Here's a Spoon Carving Knife I made (Volume 27), and the Gravity Catapult I built this week (Volume 28).

—*Lucas Fried, 12, Wayland, Mass.*





Thank you for the excellent article "Balsa Dreams" by Andrew Leonard (Volume 28). It brought back great childhood memories of building model kits with my dad. Dad started me off on stick gliders, moving up to rubber-powered kits and eventually radio control. There were even a few control-line flights. It was a tense moment every time a new one would take to the air, as we didn't want to see hours of work come crashing to the ground.

Here's a picture of us at the kitchen table in the late 1980s, covering the same Cessna that Leonard wrote about. All the memories came back: unfolding the plans and tissue, setting the windscreen and wheels aside for later, and laying out the parts on wax paper that was rolled out over the plans.

We each still build models to this day and make the pilgrimage every year to Toledo, Ohio, for the big radio control show to get primed for the next season of building and flying.

—Colin Rickards, Hamilton, Ontario

I really liked Volume 25. It showed me ways to get started with Arduino microcontrollers ("Primer: Make and Use an Arduino") and informed me of a programming software that's visual like Lego Mindstorms ("Modkit: Drag-and-Drop Arduino Programming"). I'm now thinking about getting an Arduino and making projects I didn't think I could possibly make. Thanks!

—Ethan Durrant, San Francisco

I'm writing for all of us who don't use Arduinos but are still able to make and program amazing devices. I'm seeing the magazine drastically gravitating to Arduino (all variations are sold in the Maker Shed ... hmm). It doesn't matter what microcontroller you use; creating what you want is ultimately more important. It's time to stop overhyping Arduino's impact and provide options and alternatives with their advantages and disadvantages — such as the BASIC Stamp, Parallax Propeller, Pololu Orangutan series, or Wiring Microcontroller (the original Arduino).

And what ever happened to the official MAKE Controller Kit? It seems to have faded into obscurity by your own doing.

—Will Cannady, Bronx, N.Y.

PROJECTS EDITOR KEITH HAMMOND REPLIES: We're fans of all kinds of microcontrollers. In MAKE Volume 25 we compared eight different micros, including BASIC Stamp 2, PICAXE, and Propeller ("Getting Started with Microcontrollers"). Arduino is hot and people are excited by the possibilities. The hype will diminish over time. But Arduino is cheap, beginner-friendly, and has a huge code base, which is why it's many makers' first choice.

The MAKE Controller Kit (makershed.com #MKMT3) is good for complex projects, with its integrated networking and driver circuitry. But since 2010, the Netduino (#MKND01) has been a very successful alternative.

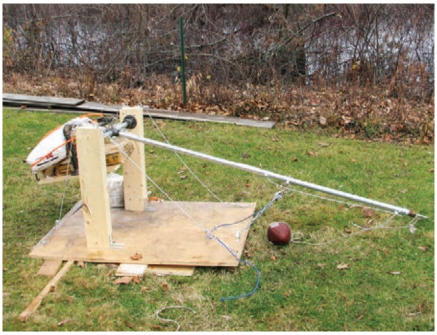
MAKE AMENDS

In Volume 27's "Yellow Drum Machine," the AXE020's pins 00–07 have their outputs (white) on the left, and +5V (red) on the right. The corrected diagram is online at makeprojects.com/project/y/1077.

In Volume 27's "Roomba Recon," the Linksys WRT-SL54GS router is hard to find and resists substitution. We apologize for any frustration, and hope to document an alternative.

In Volume 28's "Toolbox," John Baichtal's supersoaker review was misattributed to Jason Babler. Sorry, J.B.!

In Volume 28's "Coffee Table MAME Console," the arcade buttons can be OSBF-30 or OSBF-24. Also, quick disconnects are a nice upgrade from spade connectors: 0.187" for joystick, and 0.110" for buttons.



Jan	Feb	Mar
Apr	May	Jun
July	Aug	Sept
Oct	Nov	Dec

MAKER'S CALENDAR

Compiled by William Gurstelle

Our favorite events from around the world.

RoboGames

April 20–22, San Mateo, Calif.

RoboGames claims to be the Olympics of robotics with more than 50 different events: combat robots, firefighters, Lego bots, hockey bots, walking humanoids, soccer bots, sumo bots, and even androids that do kung fu. robogames.net

FEBRUARY

» Transmediale

Feb. 1–5, Berlin

More than 30,000 people participated in Transmediale events last year, making it one of Europe's largest digital art, culture, and technology festivals, featuring exhibitions, conferences, film and video programs, and live performances. transmediale.de

» The Little Shop of Physics Open House

Feb. 25, Fort Collins, Colo.

Each year, the science outreach program at Colorado State University opens its doors to the public and features hundreds of clever and sometimes edgy experiments, as well as a number of presentations, aimed at teaching people that science is something anyone can do. littleshop.physics.colostate.edu/openhouse.html

MARCH

» SXSW Accelerator

March 12–14, Austin, Texas

Wonder who comes up with all those apps? Wonder no more. SXSW Accelerator is a showcase of cutting-edge social media, mobile applications, and web entertainment demos. Developers from around the world present their best work, hoping for props from the assembled technorati. sxsw.com/interactive/accelerator

» Expo Day

March 24, San Diego, Calif.

The San Diego Festival of Science and Engineering is arguably the largest celebration of science on the West Coast. The highlight is Expo Day, where over 20,000 students, scientists, and educators take part in science and tech-related activities. sdsciencefestival.com

» Blossom Kite Festival

March 31, Washington, D.C.

Featuring a no-holds-barred Rokkaku battle where the last kite flying wins, this festival showcases a variety of kite competitions and demonstrations. Bring your own kite or make one there to fly on the National Mall. nationalcherryblossomfestival.org

APRIL

» Fisherman's Festival Wooden Boat Challenge

April 28–29, Bodega Bay, Calif.

Teams of four compete to build a boat, start to finish, in just three hours, and then sail it around the harbor to prove its seaworthiness. No power tools allowed, but life jackets and bailing equipment are required. bbfishfest.org

» STEM Book Fair

April 28–29, Washington, D.C.

The USA Science and Engineering Festival Book Fair will be the first of its kind in the nation. Over 30 science, technology, and DIY authors will be on hand. usasciencefestival.org/bookfair

*** IMPORTANT: Times, dates, locations, and events are subject to change. Verify all information before making plans to attend.**

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Dave Schumaker

MAKING TROUBLE

By Saul Griffith, Omnivorous Inventor

MENTORing Kids into Makers

DARPA IS THE DEFENSE ADVANCED Research Projects Agency. It used to be called ARPA, and it was ARPA who funded the creation of the internet. Think of DARPA as the high-risk R&D sector of the U. S. Department of Defense. Sometimes the things they fund sound crazy, and sometimes they even are, but I personally think that they fund the more ambitious science and engineering projects in this country and get great results. Google might be claiming credit for the autonomous car, but remember that the guy who is running that program cut his teeth in the DARPA Grand Challenge autonomous vehicle race.

I worked under some DARPA programs during grad school and have participated in their programs since being in the commercial sector. I was quite surprised, and in many ways delighted, when DARPA requested proposals for a program called MENTOR that is aimed at addressing the shortfall of well-trained scientists and engineers in the U.S. The goal is to excite and enable a new generation of hands-on makers who can collaborate and co-design more complex things than have ever been built before (at least that is my interpretation of their goals). I was even more surprised and delighted when the venerable Dale Dougherty — the Pied Piper of makers everywhere — and I successfully received an award to tackle this grand and noble goal through our companies O'Reilly Media and Otherlab.

We've been asked to achieve hands-on education in 1,000 high schools in the U.S., and even around the world, within 4 years, at an incredibly low cost. There are few educational programs that have ever gotten to that scale through voluntary participation, FIRST Robotics, a really great robot competition, being the exceptional exception. But can we do more than robots? Can we appeal to a broader audience? We believe we can (it's why we applied), and we believe it's about enabling the maker spirit in everyone, about better collaboration tools for makers, and about more self-directed learning.

Send us your ideas, your offers of help, your good and bad educational experiences.

I won't go into great detail about our exact proposal, but we do know that we need help. We have a solid set of plans, but the thing about getting a mandate to improve hands-on education is that, inevitably, one very quickly wants to fix everything. I think both Dale and I are barely containing our desire to shake things up, and our plans are getting more ambitious by the day, not less. We know that we will need *a lot* of help. This column will be my last traditional column of the Making Trouble variety; starting in the next issue, it will be a how-to.

So with these last few column inches, I send a request to all of you to send us your ideas, your offers of help, your good and bad educational experiences. Although we can't change our plan too much, I'd especially like to hear what you would do if you were tasked with reforming STEM (science, technology, engineering, and math) education. Send your ideas to mentor@otherlab.com.

First imagine you have infinite money to fix the problem (wouldn't that be nice?). Then imagine you have a smaller budget than the average high school newspaper. Makers, let's make education better, together.

Saul Griffith is chief troublemaker at otherlab.com.

Made On Earth
Reports from the world of backyard technology

Tom Van Eynde

Dead Laptops

Chicago-based artist **Michael Dinges**' work is reminiscent of scrimshaw and trench art. For the uninitiated, scrimshaw began in the 18th century, when sailors started carving designs into teeth, bones, and tusks. Trench art involved decorating spent artillery shell and bullet casings to create ornamental items.

Dinges evolved from scratching images into PVC pipe elbows with an engraving needle to using a Dremel. Soon he found a new "canvas" of sorts: the plastic shells of discarded laptops. The result is the *Dead Laptops Series* of engraved white iBooks that are dense with images and text. The illustrations are a 19th-century graphic style but express very 21st-century concerns about privacy and the environment. He rubs black acrylic paint onto the design, allowing it to fill the engraved depressions, then wipes it off.

"There's kind of a patina of experience there, inherent in the object, but you can't have access to it anymore," Dinges says of the lapsed laptops, which sell for $5,500.

Several were exhibited at Tekserve, an independent Macintosh computer store in Manhattan. The exhibit was the first in the store's new gallery space and also a homecoming of sorts: when Dinges contacted Tekserve out of the blue in 2008, they sent him eight dead iBooks. In summer 2011, the wife of one of the store's owners stumbled on Dinges' work in Chicago and proposed that he exhibit at Tekserve.

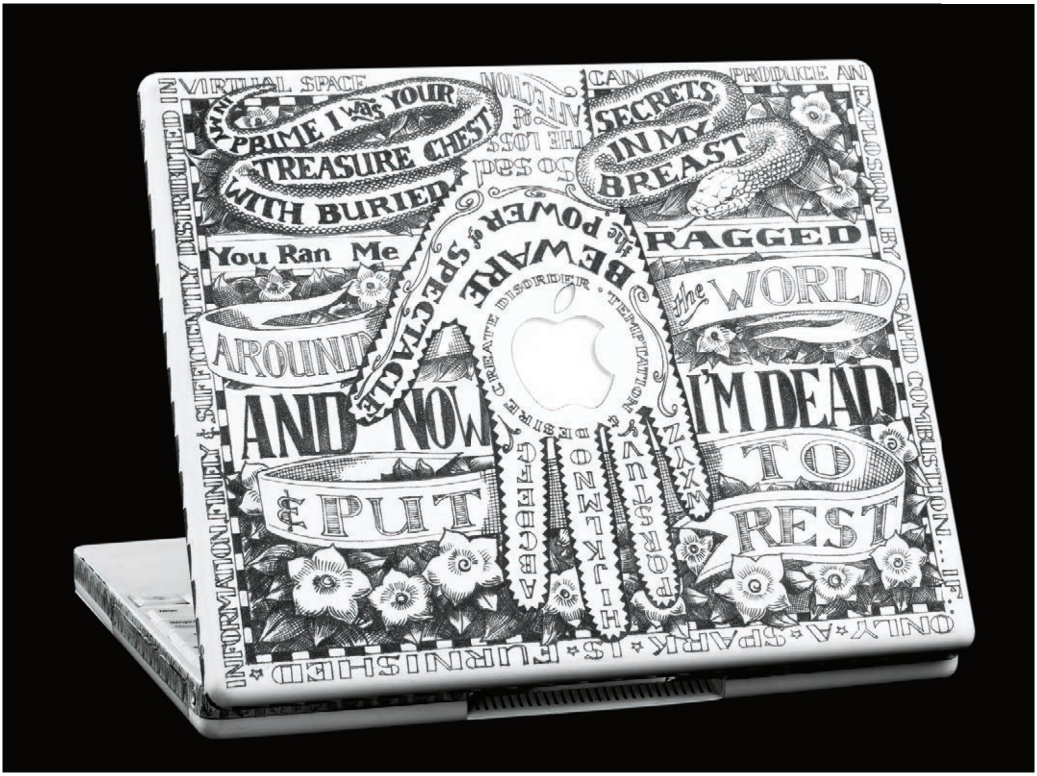
"While we often donate [old computers] to artists, students, and noncommercial entities as a community service, we don't often see the fruits of our donations," says Tekserve's Dick Demenus.

Or, as Dinges puts it: "What goes around, comes around."

—Jon Kalish

» **Laptop Canvases:** michaeldinges.com


MY SPACE
YOU TUBE
FACEBOOK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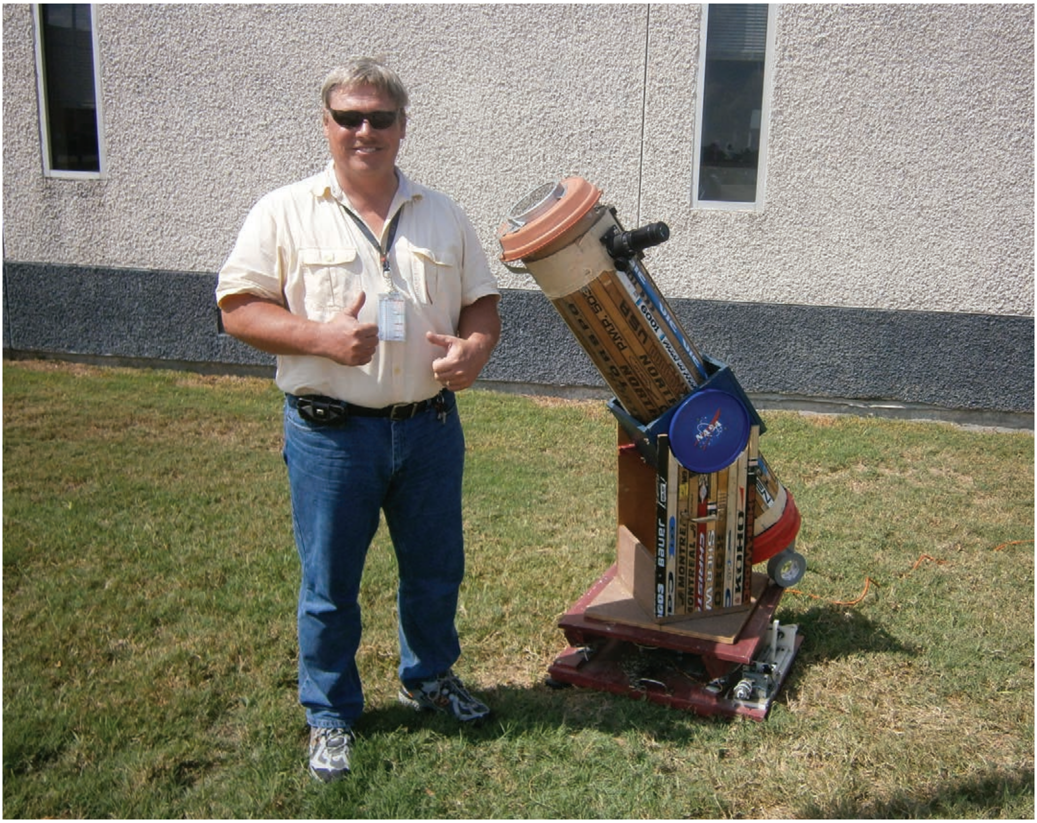


Slap Shot to the Moon

When **Jeff Stone** and his wife, **Susan**, decided to build a telescope, run-of-the-mill building materials just wouldn't do.

"My wife has been playing hockey since junior high school and had a pile of sticks available," says Stone. "So it seemed like the logical material to use." The scope is an 8-inch f/6 Dobsonian, and what instantly sets it apart is that it's built primarily out of hockey sticks.

"Most of them are leftovers from broken ones my wife collected over the years," Stone explains. "There are a couple of special ones that were used by players from the Houston Aeros of the late 1970s, including Mark Howe, one of Gordie Howe's sons."

Stone had always wanted a telescope and had even thought about building one. After he and his wife met a group of amateur astronomers on a trip with the Johnson Space Center Astronomical Society, they realized handmade telescopes were well within their skill set and decided to make one themselves.

"The project was very intense, especially the mirror-making part," he notes.

Stone worked in the space shuttle division of the Mission Control Center at Johnson Space Center, and would take the telescope in to share with his co-workers.

"During shuttle flights, there's a short time every orbit that we lose communications with the vehicle, so the controllers take a quick break," he says. "I'd leave the scope on the sidewalk outside so we could run down to have a quick look at the moon, maybe a planet or two, or a bright double star if we were lucky."

Stone says he's made many friends and has had lots of interesting conversations thanks to the telescope. "Building it, especially out of hockey sticks, is one of the most rewarding things I've ever done."

—Rachel Hobson

Adam Lisowski

Pipe Dreams

In a public park near the German city of Essen, on redeveloped industrial land about 30 miles east of the Dutch border, there is a very unusual hotel. Conceived by Austrian artist **Andreas Strauss** and implemented by a team of administrators and web developers, including **Gunda Wiesner**, **Georg Brunader**, **Olivia Schütz**, **Claudia Kogler**, and **Nikolaus Diemannsberger**, Dasparkhotel is a pay-what-you-want travel lodge with five rooms, each built from a 20,000-pound section of 7-foot-diameter concrete drain pipe.

The rear of each pipe section is sealed, and the front has a door with a pushbutton code lock. Reservations, available from May through October of each year, are made online and confirmed with an email containing a code that will unlock the right door on the reserved days. Staff appear on site only to clean and turn the rooms, and collect whatever payment travelers leave behind.

Each room has a raised plywood sleeping platform topped with a foam double mattress, which fills most of the pipe, along with a cabinet full of fresh sheets and pillows. A round skylight provides natural lighting during the day, and a small bedside lamp allows for nighttime reading. The curvature of the pipe under the bed makes for a handy place to store luggage, and the rear wall of each room is decorated with a hand-painted mural.

The rooms are wired with European-standard 220V power, and each provides a single AC outlet for using and charging personal electronics. There are no dedicated toilets, showers, food vendors, or water supplies, but all are readily available in the surrounding public space.

—Sean Michael Ragan

» **German Hospitality:** dasparkhotel.net

Andreas Strauss

Solar Dune Buggy

Brothers **Michael and Kenny Ham** have a goal: to create cheap electric vehicles that get people interested in renewable energy. In 2009, they built Three-Wheeled Electric Alternative by KinAestheticWind (TWEAK), a solar-powered three-wheeler. "We wanted a vehicle that could recharge itself," says Kenny.

For help with their project, they offered an extended learning course at the University of New Mexico's Los Alamos campus. "Our students (eight men and two women) turned out to be the perfect blend of age and experience," says Michael, 30, a Ph.D. physicist in computer vision research at the Los Alamos National Laboratory. "They were solving problems in ways we'd never dreamed."

The group took a heap of parts — including an old classroom seat, the steering and suspension components from a VW Beetle, a sealed lead-acid battery, a solar battery charger, and three motorcycle tires — and turned them into a dune buggy-like ride, all for about $1,000. Two cordless drills supplied power to the rear wheel through a series of old bicycle parts and a motorcycle chain.

"One mistake we made was buying a 12V solar panel to charge a 36V battery pack," explains Kenny, 24, a mechanical engineering technology student at Kansas State University. "We fixed it by creating a circuit that allowed the pack to run at 36V and switch to 12V for recharging."

Though heavy and slow (it had a combined horsepower of 2), it ran. "We always called TWEAK 'Prototype Zero' because we knew it was going to be more of a learning experience than anything else," Michael admits.

Next up: ApocalypsEV-1, a compact, street-legal electric ATV.

—Laura Kiniry

» **Sun Cruiser:** makezine.com/go/tweak

Lissie Ham

Matthew Borgatti

Organ Donor

Multitalented maker **Matthew Borgatti** vividly recalls the monster pipe organ shoved into every nook and cranny of a home in his suburban childhood neighborhood. "I remember touring it as a Boy Scout, watching the elderly couple who owned the place pull up sections of the floor to reveal wooden organ pipes cut at odd angles to bend around the joists and conduit." It was then, as he sat at the console playing "The Imperial March," that Borgatti's love affair was sealed.

Pipe organs have since gone the way of the dinosaur, as many churches have disposed of the behemoths in favor of PA systems. To Borgatti, 26, the biggest shame of the pipe organ's demise is that only a select group of musicians ever gets to play them. "If I could create something mobile, where I could turn any space into a pipe organ and make it MIDI powered, I could create interactive installations to spread the love of this awesome instrument." He did just that, and thus the Anywhere Organ was born.

Borgatti spent a year designing, building, harvesting parts, and raising funds, but now that the groundwork is laid, expansion is easy. All the parts are driven by simple tables in CAD, so whenever he acquires reclaimed pipes, he plugs in measurements, the organ patterns are generated, and the housing units are laser-cut from ¾-inch plywood. In action, the organ uses a j-Omega MTP-8 to control the valves from a MIDI signal, and has a USB-to-MIDI converter running from his laptop. Naturally, the project is open source.

Now Borgatti hopes to make it "bigger, better, weirder." When he installed it at Maker Faire New York 2011, a local robotics team used it to rock a fantastic rendition of Journey's "Don't Stop Believin'." What could be more perfect? —*Goli Mohammadi*

» More Borgatti: har.ms

Gravity Harps for Björk

I had tried to stop making musical machines but kept getting offers I couldn't refuse. I thought I'd quit this crazy business if I could just pull off one last job — the big one. Then I met Björk at the MIT Media Lab. She needed some musical robots. This was big.

Björk had an amazing vision. She wanted to create technologies that harness forces of nature to play music. She wanted to use gravity to play a new song, "Solstice," preferably with a giant pendulum. "Solstice" has unusual time signatures and a nonrepeating structure. I couldn't play it with one big metronome, but maybe I could use a few pendulums and deconstruct the patterns like a Fourier transform. How hard could it be?

Hard enough, it turns out. Then the project changed from a film into a live tour. There were so many prototypes and complete redesigns. It expanded to 30 feet in diameter and 20 feet tall — a 38-pendulum behemoth with 152 computer-controlled motors. The graceful jellyfish design was becoming coldly industrial. Menacing. Literally dangerous. Björk and I were both having bad dreams about it, and we finally told each other.

With only 30 days left, we started over from scratch. I drew a new, simpler design: four synchronized pendulums with four cylindrical harps that could rotate to play different notes. Our small crew worked around the clock to build four complete, iterative prototypes. On the 30th day, we shipped my final musical machine across the sea to debut with Björk's new album, *Biophilia*, at the Manchester International Festival.

So, this was the big one. But instead of being my swan song, it filled me with ideas and excitement for more musical machines. Maybe I was never serious about quitting.

—Andy Cavatorta

» **Sweet Sound of Gravity:** makezine.com/go/cavatorta

James Patten

Charles Guan

DIY Segway

Mechanical engineering student **Charles Guan** built a homemade Segway, called the Segfault, with some rather impressive geek cred. It uses absolutely no software, microprocessors, or other digital logic. He replicated the electric vehicle using a fully analog system made up of just op-amps and passive components. It's no surprise — the MIT grad student has been building robots and other odd vehicles since he was 11 years old.

A classic inverted pendulum problem, the Segway system is naturally unstable — a point that was proven when, ironically, the company's owner died test-driving a new all-terrain model. The system's instability stems from having the mass located above its pivot point. This gives it two degrees of freedom — the pendulum's angle and the horizontal freedom of the base.

"The job of the [Segway's digital] controller is to keep the base under the center of gravity [you] at all times. Most Segway control code you will find does this if you analyze it in terms of discrete-time (digital) controls," explains Guan.

The Segfault uses a gyroscope like the Segway — and even an accelerometer like that found in an iPhone — but it can't yet compensate for the lean you experience at high speeds. So the vehicle tops out at around 8 miles per hour. That is, if you wish to not be thrown from the vehicle. Using a 35-cell lithium nanophosphate battery pack, the Segfault charges in about 10 minutes and has an operational time of about 2 hours.

Unfortunately, analog components are highly sensitive to ambient temperature and voltage noise, so obtaining one for a game of Segway polo is unlikely.

—Jerry James Stone

» **Segway, Analog-Style:** makezine.com/go/segfault

MAKING MAKERS

By AnnMarie Thomas, Engineer Educator

Real Tools for Kids

RECENTLY, WHILE LOOKING ONLINE FOR woodworking tools appropriately sized for my preschool daughter, I came across some construction sets geared toward children. Thinking fondly of the sets I had when I was little, I looked closely to see if I could find one suited for my kids.

I was intrigued by one kit that promised "real" construction play. While the kits that I played with in elementary school typically included glue, nails, and a rough picture of something I could build with a hammer and maybe a saw, this kit included foam "wood," plastic tools, and plastic nails. The promotional materials stressed that these are "real materials" and "real tools." Real: yes. Realistic: no.

The really surprising thing was that this toy is labeled for children ages 6+ and, on Amazon, has a manufacturer's recommended age range of 6–15. Minutes earlier I'd been confidently pricing hand drills and hammers. Now this toy seemed to be telling me I should wait on those tools until my daughter reaches middle school. So how old is old enough to hand kids real tools?

Making objects is similar to making music. We would think it outrageous to wait until a student reaches university to give them their first non-toy musical instrument. However, many students reach their first year of college without much experience with tools. I recently spoke to an engineering professor who mentioned that when he asked a class of 35 first-year engineering students how many had used a drill press before, not a single hand went up. How many had taken apart one of their toys when they were younger? Again, not a single student raised a hand. And that's in a roomful of future engineers.

The more I research children and tool use, the more I notice how things have changed. Kids were once trusted with real, metal tools. In the early 20th century, it was common for elementary schools to teach manual training. In 1900, Frank Ball, a teacher at the University Elementary School in Chicago, wrote, "At the present time no thoroughly equipped school is complete without its department of manual training or construction work." A book written in 1964 by John Feirer and John Lindbeck, of the Industrial Education Department at Western Michigan University, talks about outfitting elementary school shops and advises that the tools should be maintained well, since "the sharp, well-cared-for tool is safe, easy and fun to use." Very rarely these days do we hear "fun," "sharp," and "elementary school" in the same conversation.

As a parent and a teacher, I understand the fear of injuries, and suspect it's one of the reasons behind the decline in kids gaining hands-on skills. When it comes to tools, our risk aversion is causing more harm than good. The promotional video for the abovementioned "real" construction set showed how safe the tools are by having a child saw his hand with no injury. My 16-month-old daughter has plastic tools for now, but I'll definitely correct her if I see her sawing her arm. We don't do that with real tools, so I wouldn't want her to do it with her plastic tools.

Combine an eager child, real tools and materials, appropriate training, and supervision, and you'll be surprised by the results. More importantly, you'll see a young maker who is gaining a useful skill and confidence in her ability to bring ideas to life.

AnnMarie Thomas teaches in the engineering and engineering education programs at the University of St. Thomas in St. Paul, Minn. She's also the mother of two young makers.

COUNTRY SCIENTIST

By Forrest M. Mims III, Amateur Scientist

Track the Leading Greenhouse Gas

FOR AS LITTLE AS $20, YOU CAN BEGIN tracking the atmosphere's most important greenhouse gas, water vapor. And you can do so at any time, day or night, so long as the sky directly above you is cloud-free. This is a remarkable capability, especially since your measurements can have real scientific value if you make them at least once a day, weather permitting, from the same location.

Greenhouse Gases

The gases in the atmosphere that contribute to the warming of Earth are known as greenhouse gases. The best-known greenhouse gas is carbon dioxide, which plays crucial roles in the cycle of life. Every flower, fruit, tree, and animal is partially built from carbon extracted from the atmosphere. While carbon dioxide forms only about 0.039% of the atmosphere, it's increasing due to burning fossil fuels.

Water vapor is the king of the greenhouse gases, for it alone keeps the temperature of Earth warm enough to prevent the entire planet from freezing. Water vapor provides the precipitation that nourishes life, erodes rock, fills reservoirs, and provides hydroelectric power. The percentage of water vapor in the air varies dramatically depending on location, season, weather, and altitude.

The role of water vapor in regulating temperature becomes obvious when dry, cool air behind a cold front replaces moist, warm air. The same effect is observed when the air becomes both dryer and cooler when hiking or driving up a mountain.

You can measure water vapor in the air around you with various kinds of humidity instruments. But these tools don't measure the total water vapor layer that is so important to the natural greenhouse effect. Meteorologists call this precipitable water (PW) or integrated PW (IPW), the equivalent depth of liquid water in a vertical column through the atmosphere.

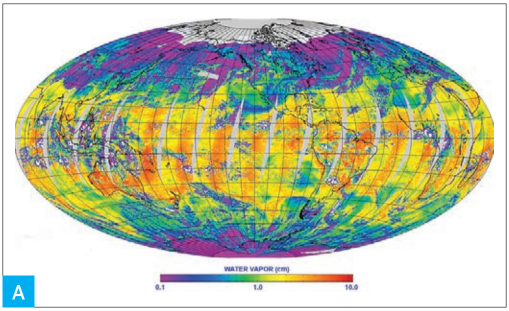
Weather balloons and a network of GPS receivers around the United States measure the total water vapor. Several satellites measure it from space, but they don't necessarily measure it through the entire atmosphere.

Join me and begin measuring PW, the layer of water vapor over your location. Since 1990 I've used an LED sun photometer to measure PW. For the past several years I've been using an even simpler method that anyone can use. It's as accurate as a sun photometer (about +/−10%) and it works day and night.

Using an Infrared Thermometer to Measure Total Water Vapor

Most of the visible sunlight arriving at Earth passes through the atmosphere and warms the water, soil, rocks, plants, roads, and buildings at the surface. All these warmed materials then emit infrared light, which allows their temperature to be measured with an infrared thermometer. Some of the infrared goes into the sky, where part of it is absorbed by water vapor and other greenhouse gases. These gases are warmed by the infrared they absorb. They then re-emit infrared, some of which is radiated back to the surface.

The same IR thermometer that can measure the temperature of the ground can be pointed straight up to measure the IR returned back to the surface by water vapor. Because of the thickness of the atmosphere and the wavelength response of an IR thermometer, the temperature indicated by an IR thermometer pointed at the sky is not necessarily the "sky temperature." Instead, the temperature indicated by the thermometer is directly proportional to the infrared emitted



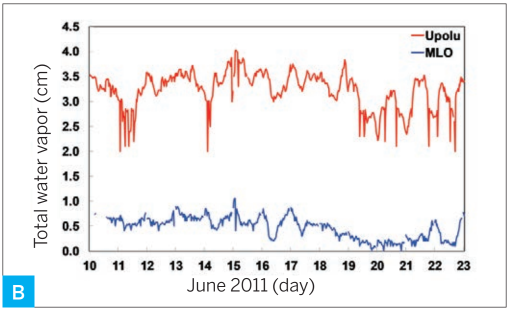
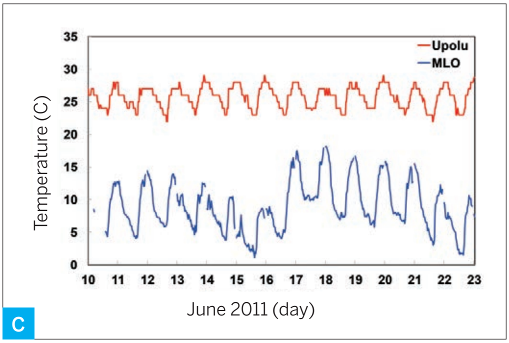


Fig. A: This color-coded image from NASA's Terra satellite on Feb. 4, 2011 shows the very high variability of total water vapor (PW) over Earth. The PW over a site in the U.S. can vary from a few millimeters after passage of a cold front to 6 centimeters or more on a warm summer day.

Figs. B and C: Vapor data from the Big Island of Hawaii. The upper chart clearly shows that there was much more water vapor over Upolu Point near sea level than over the nearby Mauna Loa Observatory, 11,200 feet above sea level, during the author's latest calibration visit. The lower chart shows how a thick blanket of water vapor keeps Upolu Point much warmer than MLO. Data from NOAA's online GPS water vapor interface (gpsmet.noaa.gov/cgi-bin/gnuplots/rti.cgi).



Forrest M. Mims III

by the water vapor directly over your location.

Try to select an IR thermometer with a minimum temperature response of –60°C or less. I have used 5 different instruments, and best results have been provided by the IRT0401 and IRT0421, both made by Kintrex. The IRT0401 is not much larger than a lipstick tube, costs around $20, and looks at a field of view (FOV) of 53°. The IRT0421 costs under $50 and has a FOV of 5°. Both thermometers provide similar results, but the IRT0421 is best when clouds are near the zenith.

Prepare to make a water vapor measurement by making sure the sky overhead is free of clouds. Face away from the sun and hold the IR thermometer in your shadow so that the sensing aperture points straight up. Press the appropriate switch to make the measurement, and record it in a notebook along with the date and time. Be sure the thermometer doesn't see your head or hat while it's held in your shadow. During summer you may need to make measurements at mid-morning or mid-afternoon, when the sun is lower.

You will find that the sky "temperature" is considerably higher on moist days than on cold days. During very dry, cold winter days, your thermometer might not indicate a temperature. You can calibrate your thermometer to convert the temperature it indicates when pointed at the sky into the total water vapor over your head. The best way is to compare a series of measurements made over a range of dry and moist days with the total water vapor measured by the nearest GPS in NOAA's water vapor network. Make as many observations as possible before doing the calibration, including multiple measurements on days with rapidly changing conditions.

Some IR thermometers are equipped with an alignment laser. It's best to block its aperture with dark tape to prevent the beam from striking your eyes or those of onlookers.

How to Calibrate an IR Thermometer for Measuring PW

1. Make lots of sky measurements over several weeks, preferably during spring or fall, when weather is rapidly changing. You can use either the thermometer's Celsius or Fahrenheit scale so long as you're consistent. Fahrenheit provides better resolution.

2. Transfer your data to a spreadsheet program. Enter the date in column A, the time in column B, and IR temperature in column C.

Fig. D: The inexpensive Kintrex IRT0401 (left) and IRT0421 (right) infrared thermometers shown here are measuring the infrared radiation radiated down to the surface by the tiny amount of water vapor in the clear sky high over Hawaii's Mauna Loa Observatory. Sometimes the sky is so dry that there is too little radiation to be measured by these IR thermometers.

Fig. E: The author recently calibrated 7 infrared thermometers against the NOAA GPS water vapor receiver (white disk on pole) at Mauna Loa Observatory.

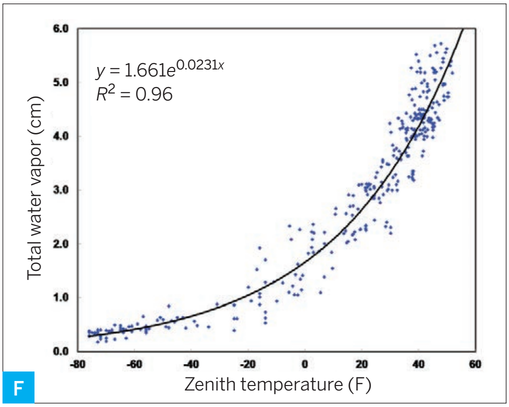


Fig. F: Scatter plot of sky temperature measured by an IRT0421 IR thermometer and PW measured by the nearest NOAA GPS from May to November 2010. The black line is the best fit to the data given by the equation at upper left. R^2 is the correlation coefficient, and 0.96 indicates very good correlation.

3. Find the NOAA GPS IPW site nearest your location at gpsmet.noaa.gov/cgi-bin/gnuplots/rti.cgi. Download the data for the range of days you measured the sky temperature.

4. The GPS PW data are averages over 30-minute intervals. In column D, enter the PW measured closest in time to each of your sky temperature readings. The GPS data will be given in UTC, so be sure to convert your times to UTC when looking for the appropriate data. Add 5 hours to EST, 6 hours to CST, 7 hours to MST, 9 hours to PST, etc.

5. Use the spreadsheet to make an XY chart in which your temperature measurements are plotted on the x-axis and the GPS PW is plotted on the y-axis.

6. Use the spreadsheet regression feature to automatically fit an exponential curve to the points on the chart. Select the options for placing on the chart the equation representing the curve and R^2, its coefficient of correlation (which indicates the goodness of the fit, with 1.0 being perfect agreement).

7. The equation for the best exponential fit to the data is the water vapor calibration formula for your IR thermometer. For most spreadsheets it will be of the form $y = e^x$, where x is an IR temperature measurement and y is the PW.

For example, the exponential formula for one of my two IRT0421 IR thermometers is $y = 1.661e^{0.0231x}$, where y is the GPS PW in centimeters and x is the address of the spreadsheet cell containing the IR temperature of the sky. The spreadsheet version of this formula is entered into a single cell as: `=1.661*EXP(0.0231*C100)`, where C100 is the cell containing x, the IR thermometer reading. The spreadsheet will automatically do the math and place the PW amount in this cell.

You can copy the formula from your calibration into all the cells in column D of your spreadsheet. This will provide the PW each time you enter a sky temperature into the adjacent column C.

Forrest M. Mims III (forrestmims.org), an amateur scientist and Rolex Award winner, was named by *Discover* magazine as one of the "50 Best Brains in Science." His books have sold more than 7 million copies.

MAKE FREE

By Cory Doctorow, Digital Rights Defender

The Half-Life of Stuff

HERE'S WHAT GETS ME EXCITED ABOUT making: it lets you build *stuff* the way we build *software*. Historically, there have been two ways to make stuff. You could be an artisan and decide how you'd work, and your stuff would be expensive, though it was pleasant to make and was often beautiful. Or you could go to a factory and be part of a process that predetermined *precisely* how you'd work, down to the finest movement; your stuff would be cheap, and though it was sometimes beautiful, it was often horrible, and it was never nice to make.

Then along came software: suddenly, you had people working like artisans, but producing like factory workers. Software tools made it cheap to coordinate the labor of lots of people, so you could run something with the efficiency of an assembly line without requiring people to work in tightly coupled ways.

You write this chunk, I'll write that chunk, and we'll use the version-control system to keep track of who's doing what, and to let us roll the code versions forward and backward when things break. And when we're done, the infinite reproducibility of software will let us sell it or give it away at industrial scale. We can work from our hammocks and outperform the cubicles!

So now here's "making," where we're using networks and software tools to coordinate our activities. We trade recipes and 3D objects, and improve them. We sit on chat channels when we're bored, and offer just-in-time mentorship to newbies who're getting started. We produce things that everyone thinks of as coming from a factory, but we make them here in our garages and offices and living rooms and basements and kitchens.

But there's a critical difference between bits and atoms: the cost of burying your mistakes. When code doesn't work, we erase it. When stuff doesn't work — or gets superseded — we try to recycle some of it, but most of it goes to landfill. And most of the stuff we work with has a duty cycle of a month or a year or two, but has a half-life of a millennium.

It's one thing to do iterative design that has you trying variation after variation in your code base; it's another thing to squander rare earths, hydrocarbons, and the like on a series of experiments. These resources are cheap, yes, but only because they externalize the cost of dealing with them to generations yet to come — that is to say, your kids and their kids.

Makers aren't the worst offenders, not by a long chalk. The world is full of stuff-mongers who make everything from Happy Meal Toys to thumb drives out of materials that future archaeologists will puzzle over in the year 3522 A.D. — and yet these objects have a useful life measured in months, or possibly a year or two. We'd be better off figuring out how to make them out of spun potato peels and straw, but here they are, in their millions, made out of absurdly long-lived polymers and metals, without a thought as to how they'll degrade into the materials stream for recycling and reuse.

But makers are supposed to be inventing the future, living as though it were the first days of a better nation. If we're to bring the glory of software-like production to the world of atoms, let's figure out how to match the duty cycle to the material life of our components. How do we build complex technical devices that are designed to fall apart (into useful materials, or compostable ones!) by the time we get bored with them?

Cory Doctorow's latest novel is *Makers* (Tor Books U.S., HarperVoyager U.K.). He lives in London and co-edits the website Boing Boing.

Maker

KYLE MACHULIS: HARDWARE HACKER

Reverse engineering guru works to unlock our personal data.

By Gary Wolf

Most of the tools Kyle Machulis makes are self-justifying. It seems futile, at first, to search for utilitarian rationale in Machulis' workshop, which he calls Nonpolynomial Labs (nonpolynomial.com). Often he makes things to find out if he can make them, and to learn something, and to have a laugh, and to inspire others.

His robots do things like automatically mix drinks for video game players based on their score. (The higher the score, the stronger the drink, which ultimately leads to a lower score, and, appropriately, a weaker drink.) Or track yo-yos in mid-spin using the Wiimote camera. Machulis also gets deeply into hardware hacking on general principle, freeing game controllers and commercial devices from the limits placed on them by the companies that build them.

I first met Machulis through the Quantified Self (a personal health tracking technology conference), where he was showing his work on a project called OpenYou (openyou.org). OpenYou is dedicated to writing open source drivers for personal data devices, including pedometers, blood pressure monitors, and scales. It's your data, after all. Why should you have to always go to the manufacturer's website to see it?

The more I got to know Machulis' work, the more intrigued I was with his vision of a world of manipulable, connectible parts, unhampered by the legacy of some marketing survey that said "nobody will want to do that."

And as programmable hardware leaves the world of games and becomes integrated into many different aspects of our personal lives, Machulis' work on hacking these systems begins to have a practical edge.

Gary Wolf is a contributing editor at *Wired* magazine, where he writes regularly about the culture of science and technology. He is also the co-founder of quantifiedself.com, a blog about "self-knowledge through numbers."

Gregory Hayes

REVERSE PSYCHOLOGY
Kyle Machulis takes apart the Keepon robotic toy in his Berkeley, Calif., home workshop.

I RECENTLY ASKED KYLE MACHULIS A FEW DIRECT QUESTIONS:

Gary Wolf: Why hack game controllers?
Kyle Machulis: Most people think of these as just controls for video games, but when you unlock the technology to be used on non-game platforms, people find new and interesting uses for them.

And they are everywhere. For game controllers to succeed in the market, they have to be priced within a certain obtainable range. Sensors that usually cost quite a bit take a huge drop in price when they become part of a game control. The Wiimote had accelerometers, an IR camera, and a Bluetooth interface, for $40! That was unheard of when it was released.

GW: What is your favorite hack?
KM: One of my favorite projects was writing software that allows open programming of the Novint Falcon haptic device (home.novint.com). It's a controller that basically allows you to feel forces in 3D, so guns kick back in a player's hand, they can feel textures on the surfaces of objects, things like that.

The Novint Falcon is a $250 version of a $30,000 research controller. Writing the drivers for it took more than just figuring out the USB protocol. There's also a ton of pretty difficult math wrapped up in figuring out the position of the end effector (the part of the controller you hold). It took collaboration with academics in a few different countries to get something usable, but it's now used in everything from molecular biology research to open source wisdom tooth removal simulation (forsslundsystems.se).

And most people don't really think of touch outside of "multi-touch" or "vibration," so having a new kind of feedback really makes their heads explode.

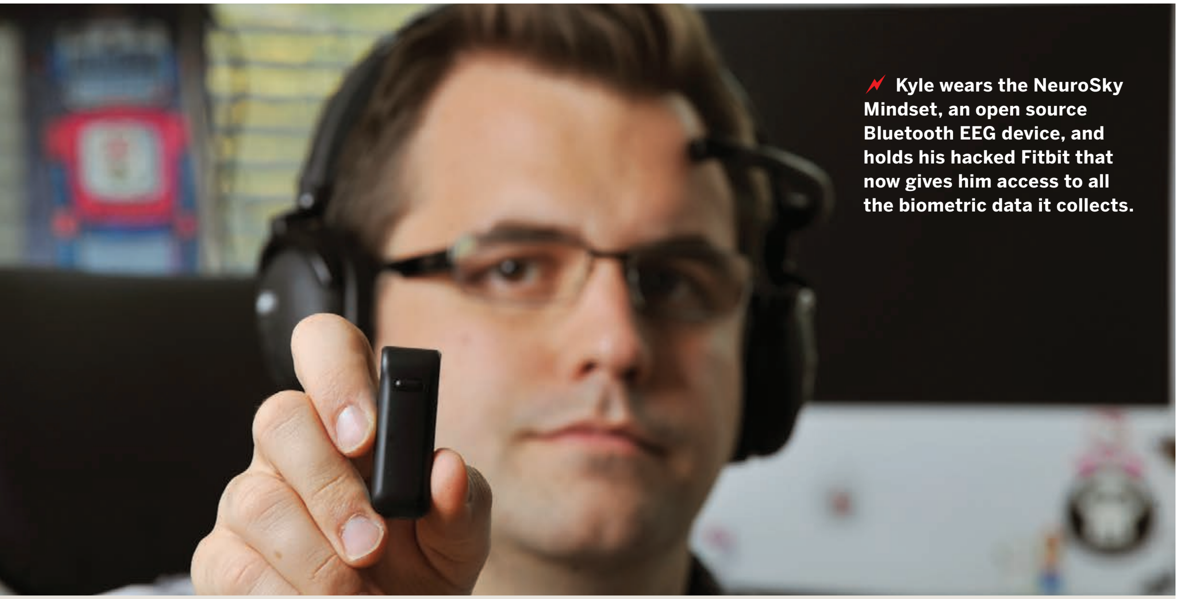
GW: By day, you work at Mozilla as a hardware engineer. What do you do there?
KM: I'm working on a completely open source, web-standards-based mobile operating system project called "Boot To Gecko." We're building a system that allows the phone to boot directly into a web browser. Basically, it's my job to make the phone dial via JavaScript.

GW: That means no App Store, no End User License Agreements for mobile software, open systems on the phone, right?
KM: It means that the phone moves in whatever direction the web does, instead of whatever direction the API that the company that makes the OS does. Think of all the trouble we have getting devices to talk to our phones. This means that as soon as there is a driver to get data from a device onto a web page, it should work on a phone as well.

GW: Why hack hardware in particular?
KM: My career after college started in educational robotics. I learned that there's a lot of hardware out there that people want to do things with but don't have the access they need, so I provide that. But I like both hardware and software equally. What I want is to have access to and know the whole stack, from the electron to the user interface.

GW: Let me ask you a Quantified Self question. What personal data tools have you been hacking?
KM: Mainly consumer hardware: Fitbit, NeuroSky and Emotiv EEGs, Omron blood pressure monitors, whatever else I can get my hands on.

GW: What's the main barrier to opening these up? Lack of software drivers?
KM: Depends on what you want to open. There are two levels: getting a single user's data, and getting everyone's data. Getting



Kyle wears the NeuroSky Mindset, an open source Bluetooth EEG device, and holds his hacked Fitbit that now gives him access to all the biometric data it collects.

a single user's data is just software drivers, yes. If the manufacturer gives the user the ability to upload data to a hosted site, we should be able to get at it without having to upload it.

The bigger problem is turning around and using that data once you have it to diagnose using a sample size larger than one. This is where the hardware manufacturers excel, as they're getting data from hundreds/thousands/millions of users that they can process, learn from, and create services on top of. But there's not really a way for users themselves to do this.

GW: So if there were open Quantified Self platforms, anybody could make an alternative data aggregation site?
KM: On the face of it, yes. But then there are the issues of hosting costs, user privacy guarantees, and so on. It's a violently complex problem, of which the engineering is the easy part.

GW: Do your parents know you do this with your time?
KM: My parents were both computer programmers, so I grew up around computers, and they have always been very encouraging.

GW: What's your attitude toward EULAs and other legal restraints on hacking hardware? Ignore, obey, or something in between?
KM: I just take the "ask forgiveness, not permission" philosophy. Of course, "forgiveness" in this case can sometimes mean, "Please stop the lawsuits."

A lot of times, though, what I'm doing is legal. Since I'm working on fairly simple hardware that communicates over USB, I "own" the line between the device and my computer. And since that's what I'm usually tapping, it's within DMCA-level legality.

I'm never really aiming to divert funds out of someone's business or be malicious. I just want things to work the way I want them to, but I don't want to have to manufacture them myself.

GW: What practical wisdom do you have for people who might want to follow in your footsteps?
KM: With reverse engineering, the big hope should be that one day, you're not needed anymore. That means we've won.

GOOD VIBRATIONS:

GROOVY MECHANICAL SOUND PLAYERS

A look back at the all-mechanical marvels that made fun sounds for over 100 years.

By Bob Knetzger

Long before iPods, MP3s, or even electricity, people recorded and listened to music and speech by all-mechanical, analog means. Thomas Edison's first important invention after setting up shop in Menlo Park, N.J., was the practical phonograph. His 1877 design featured a sharp stylus that pressed into a tinfoil cylinder. By shouting into a horn as he turned a crank, Edison caused the vibrations of his voice to make a pattern of indentations in a corkscrew groove along the surface of the spinning cylinder. When the stylus retraced that up-and-down pattern, the vibrations reproduced the sound of his voice. Edison famously demonstrated the effect by reciting the nursery rhyme "Mary Had a Little Lamb" and then playing it back.

It's telling that he chose so frivolous a passage. Although the original intent of the invention was not for entertainment (Edison was working on a way to record telegraph messages), the first application for the phonograph was in a talking doll. Unfortunately the fragile bisque-headed dolls proved too

Bob Knetzger

expensive, unreliable, and difficult for children to operate (you had to turn a crank smoothly and continuously to make the doll talk). The doll was a commercial flop, and Edison moved on to other projects.

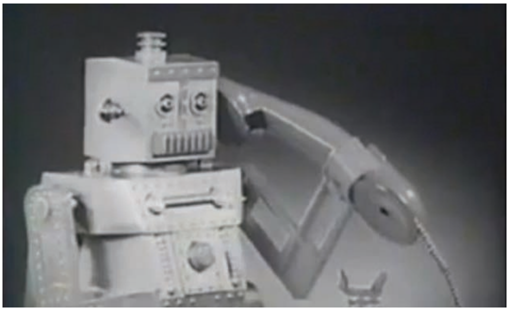
By the early 1900s others had made improvements on the phonograph by replacing the foil with wax, incising rather than impressing the grooves, and switching from individually recorded cylinders to discs that could easily be duplicated by stamping. Each of the incompatible formats had their fans. Some argued that the constant stylus speed across a cylinder together with the "hill and dale" modulation (grooves that wiggled up and down) of Edison cylinders reproduced sound better than disc format with sideways modulation, varying stylus speed, and tone arm tracking error. No matter — like the Betamax/VHS showdown, the technically inferior but more popular gramophone disc format prevailed.

Then, with the advent of radio and electronically amplified phonographs, wind-up mechanical sound players died out — until 40 years later. In 1952 Louis Marx & Co. created Robert the Robot, a boxy plastic robot that talked when you turned the crank in his back, just like Edison's doll — including the poor sound quality and hard-to-regulate speed (makezine.com/go/robert). This toy has been recently reintroduced as a collector's replica using the original tooling, but with modern electronic sound chips for better playback.

In 1960 Mattel introduced a new talking doll that was everything Edison's doll wasn't. Chatty Cathy was sturdy, great sounding, affordable, and most importantly, easy for a child to operate. Just pull the string and Cathy said one of 11 different phrases, like "Tell me a story!" or "Please take me with you!" Mattel gave her a soft vinyl head with rooted hair, and accessories like strollers and a wardrobe of themed outfits, all "sold separately" of course. Thanks in part to her nationwide TV campaign (makezine.com/go/chatty), Chatty Cathy was a big success!

She even inspired an episode of *The*

PIONEER PLAYERS (Left) Thomas Edison and his original 1877 phonograph. (Below) Marx Toys' 1952 talking toy, Robert the Robot.



Levin C. Handy (top)

Twilight Zone, "Living Doll." The voice of the similar but sinister Talky Tina doll ("My name is Talky Tina — and I don't think I like you!") was performed by June Foray, who also did the voice of the real Chatty Cathy doll, as well as those of many TV cartoon characters including Rocky the Flying Squirrel, Natasha, and the Grinch's Cindy Lou Who.

What made it all work was the cleverly designed voice unit, invented by ex-Raytheon missile engineer Jack Ryan, Mattel's in-house toy wizard. Instead of turning a crank, the child simply pulled out a string, which wound up a powerful metal spring. In the same motion, the string (ingeniously threaded right through a hole in the tone arm) automatically lifted and pulled the tone arm back to the beginning of the record.

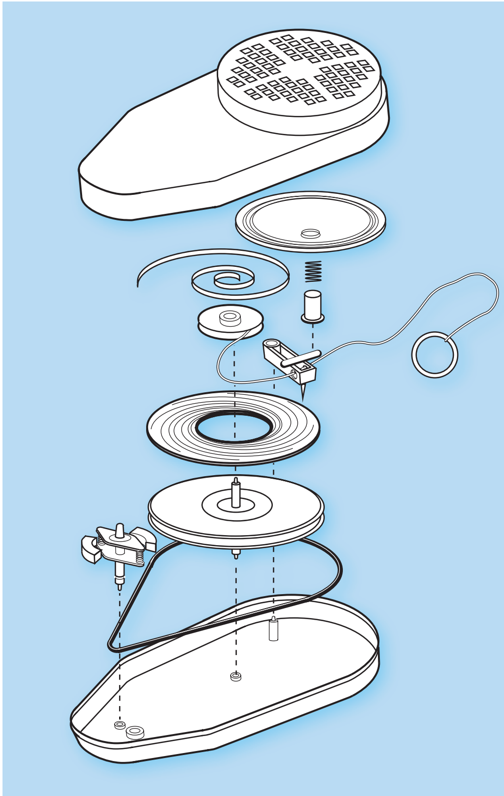
The miniature record had concentric annuli. Unlike a single continuous groove (like on an LP), the disc had multiple grooves that were interleaved and spiraled around each other. They were arranged so that the multiple lead-in grooves of the tracks were distributed around the rim, like numerals on a clock face. When the tone arm dropped on the spinning record it would land at random on any one of the tracks. "You never know what she will say next!" touted Chatty Cathy commercials.

Unlike in the gramophone, the styrene speaker cone in this voice unit was fixed in one position. A tiny spring-loaded piston pressed the needle into the hill-and-dale modulated groove. It also acoustically coupled the speaker cone to the curved ridge on top of the moving T-shaped tone arm. The record was molded out of tough, slippery nylon to be both durable and smooth running. This design produced loud, clear sounds with great fidelity. The constant pressure of the piston kept the needle in the groove so the voice unit didn't rely on gravity like a gramophone — it would work upside down, or at any angle, perfect for a toy.

To keep the record spinning at a smooth and steady speed, it was connected via a rubber belt and pulley to a die-cast zinc centrifugal regulator. Like a spinning figure skater, the arms of the regulator would move in and out in response to any variation in speed. Too slow and the spring-loaded arms snapped inward, speeding itself up. Too fast and the arms swung out, where their felted tips dragged against the housing, subtly and gently braking the speed.

Mattel continued to improve their voice unit by updating to a more elegant S-shaped negator spring, which provides constant force in a compact size (like a self-rewinding carpenter's measuring tape). The powerful spring motor had extra torque, which was used to power additional mechanical gimmicks on various toys. The Mickey Mouse Chatter Chum moved his head up and down as he talked. Shrinkin' Violet, a doll based on ABC TV's "The Funny Company," fluttered her eyelashes and moved her lips.

The same basic mechanical sound player was used in dozens and dozens of other toys: Barbie dolls, talking books and games, puppets, and lots more. Because these miniature sound makers reproduced recognizable voices and sounds, they were a natural for items that were based on well-known characters with famous catch phrases. Just pull the string to hear Robin Williams as Mork from Ork say "Nanoo, Nanoo," Herschel Bernardi



PULL MY STRING (This page): Mattel's ingenious voice unit with interleaved spiral grooves. (Opposite): Sound-making toys from the past and present.

as Charlie the Tuna say "Hey, Stahkist, I gaht good taste!," or Mel Blanc as Bugs Bunny say "What's up, doc?" The list of character voice toys was endless: Casper the Ghost, Beany and Cecil, Doctor Doolittle, The Monkees, Herman Munster, Woody Woodpecker, Flip Wilson, and Fred Flintstone, to name a few.

The pull-my-string action was so iconic that it was used to trigger the *Toy Story* Talking Woody Doll, even though this toy's sound player was entirely electronic.

Bob Knetzger

Edison's first application for his phonograph was in a talking doll. It was a commercial flop.

GGRP (bottom right)

The longest-lived pull-string product line was the Fisher-Price See 'n Say. A pointer attached to the record's shaft allowed kids to select the sound track they wanted to hear. Just point and pull to hear nursery rhymes, alphabet, numbers, or animal sounds. "The cow says mmmMMOOooooo!"

Even after the 1970s, when all-electronic talking toys were introduced, these mechanical players offered an inexpensive way to reproduce natural voices and sound effects. One toy from 1982, Mattel's Teach And Learn Computer (TLC), combined Victorian-era and Space Age technologies. A microprocessor was used to accurately drop the tone arm onto a spinning record, landing at the exact instant to play the desired single track out of 40 different lead-in grooves whirling by.

Mechanical sound players continue today in novelty applications. Go to makeprojects.com/v/29 to see some short videos of a Japanese, all-cardboard record player toy and thumbnail-activated talking strips.

In 2010, GGRP, a Canadian recording studio and production company, created an award-winning promotional piece featuring a cardboard record player that was powered by twirling a pencil (makezine.com/go/ggrp).

Coming full circle, you can find plastic reproduction kits of all-mechanical phonographs. Japanese kit maker Gakken updated Edison's design to use plastic cups instead of tinfoil cylinders, and theirs is powered by a small electric motor instead of a hand crank. There's also a Berliner Gramophone Kit disc cutter with a wind-up motor. Groovy, baby!

Bob Knetzger is an inventor/designer with 30 years' experience making all kinds of toys and other fun stuff.

DIY SUPERHUMAN

8 WAYS TO MOD YOUR BOD

MEET CAROL REILEY

Surgical roboticist by day, health hardware hacker by night.

BY TODD LAPPIN

HAVE YOU EVER MADE A ROBOT THAT didn't work right, at least at first? In hobby robotics this is no big deal, and it still isn't the end of the world with industrial robots, but with surgical robotics, being one millimeter off can mean life or death — or at least complications. Welcome to Carol Reiley's world. She's the co-maker and co-author of the Air Guitar Hero and Blood Pressure Monitor projects featured in this issue of MAKE, and she recently finished a Ph.D. in surgical robotics from Johns Hopkins, where she (among other things) developed precise force-feedback arms for remotely tying surgical knots.

Now Reiley works at Intuitive Surgical, makers of the da Vinci Surgical System. These robots don't work autonomously; instead, human doctors use them to execute precise surgical procedures or to augment their ability to see inside a patient's body. The improved precision and reduced trauma of robotic surgery translates to less patient pain and faster recovery times.

Yet even as she spends her days helping to develop multi-million-dollar surgical robots, Reiley remains active as a maker who enjoys looking for simple, low-cost ways to solve big healthcare problems. MAKE spoke with her to learn how she found her niche and how she wants to change surgery in the decades ahead.


Garry McLeod

What led you to surgical robotics?

My dad is an engineer, and he taught me and my brother how to program computers when I was in eighth grade. I've always had an interest in mixing computing and engineering.

I never really wanted to be a doctor, but all through high school I volunteered at a hospital. I saw a lot there and realized that I wanted to have an impact. As a doctor you save one life at a time, but as an engineer I could build something that could change the way surgery is performed and potentially save millions of lives.

How did you begin working with robots?

As an undergrad at Santa Clara University, I was very fortunate to work with a professor who had a laboratory for land, sea, and space robots. It was very hands-on, and underwater robotics just seemed so cool! We built a low-cost, underwater, remotely controlled vehicle that operated in a little pool. I got a scuba license, we went out into the field — that's how I started building robots.

It's quite a leap to go from underwater robots to the operating room!

My professors have had such an amazing influence on my life. As a grad student I met a professor at Hopkins who was doing a lot of work with surgical robotics. I realized there were so many problems that needed to be solved, like how do you give robots a sense of touch, so a doctor using a surgical robot can feel hardness or texture. I ended up doing my master's thesis on haptic technology.

Is there a proper balance between robotic technology and human expertise?

I've never been interested in robot autonomy; I'm much more interested in human-machine interaction. I don't want robots to be able to operate on you autonomously, but I do want computers to understand what's going on, so they can assist doctors in ways that even a human assistant could not — say, with an extra arm, or by providing enhanced vision.

Right now I'm doing an internship at Intuitive Surgical, the company that makes the da Vinci surgical robot (youtu.be/rP25mga2x8M), which can already scale motions, magnify views, and provide 3D vision. Robots can help a doctor become a Super Surgeon.

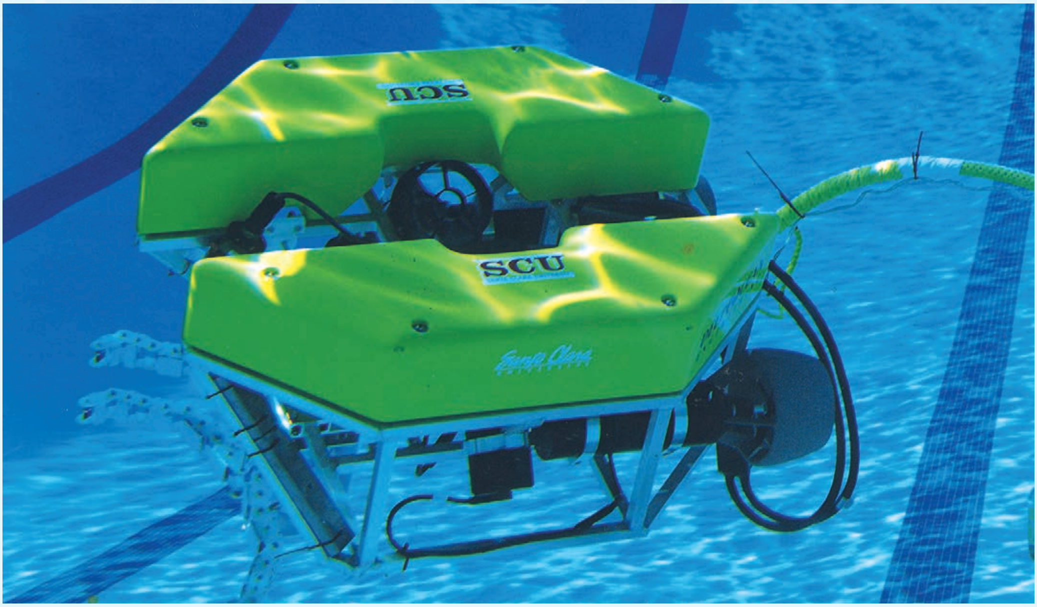
How do doctors control surgical robots?

That's what I like to think about — how humans interact with the machines. There's still a lot of work to be done in this area. Whatever a robot "feels," we want to convey that feedback to a doctor in a realistic way. That can mean a slave robot — a physical device that gives direct feedback to a doctor in a physical environment. Or it can be a virtual environment, where conditions are simulated on a computer to replicate and manipulate a physical environment.

In either case, the goal is to provide a more realistic experience. That might mean an immersive sense of touch, with attributes such as weight, pressure, and feel. Or, in a virtual environment, to provide additional information like numerical data. I want things to feel more natural, and to filter out extraneous information.

It's hard to imagine a doctor performing surgery without some tactile feedback.

In open-hand surgery, a surgeon can feel the hardness of tissue, the pressure of surrounding pieces of anatomy, any physical changes that happen over the course of a procedure, and so on. Surgical robots work in a very difficult environment. Unlike industrial robots, which function more or less in free space, surgical robots operate inside very small incisions in the body. The constrained space means there are a lot of physical pressures on the surgical tools, which makes it very hard to determine which of those pressures should be translated into haptic feedback. Plus the sensors on the robotic arms have to be sterilized in an autoclave, which is very hard on them. Haptics are viable in research, but in the real world, it's much more complicated.



POOL BOT: Triton RUV (remote underwater vehicle) from Prof. Chris Kitts' robotics class at Santa Clara University, where Carol Reiley began working with robots.

Santa Clara University Robotic Systems Laboratory

So where are the frontiers in surgical robotics?

Surgical robots don't have intelligence right now, but that's the kind of thing I worked on in grad school. I see adding that intelligence as the next level; that's how we can really revolutionize the operating room. There are three frontiers: to have robots working in the operating room that function like true assistants, so they start to act and anticipate like an experienced surgical nurse throughout the course of a procedure. Another frontier is augmentation, with capabilities like augmented motion to guide the surgeon who is performing a task, or augmented vision, to give surgeons capabilities they really wouldn't have otherwise. The third frontier is to automate tasks that are tedious, repetitive, or boring — like closing up a surgical incision.

That all sounds great, but it also sounds expensive.

It is! Today, a surgical robot costs around $2 million. But that's also why I've launched a project called TinkerBelle Laboratories. TinkerBelle is a group of engineers I've gotten to know, and together we try to develop simple solutions to attack big, global problems. In healthcare, for example, many pregnant women in the developing world have hypertension, which can cause a lot of health problems. But in those kinds of environments, there are relatively few people who know how to take a proper blood pressure reading. So we created an automated blood pressure device that's very easy to use, doesn't require any training, and could be produced at very low cost. [Build one yourself on page 70.]

I tend to think on two different levels at the same time. I love being able to work with the most sophisticated robotic machines in the world, but I also love working on problems that need low-cost solutions. I realize those two impulses pull in opposite directions, but they're both really interesting to me because they require you to design and build things in very different ways.

Todd Lappin is the founder of Telstar Logistics, a leading provider of integrated services via land, air, sea, and space. He also edits Bernalwood, a blog about San Francisco's Bernal Heights neighborhood.

AIR GUITAR HERO

Drop the controller and shred songs using the electrical signals from your arm muscles.

BY ROBERT ARMIGER AND CAROL REILEY

We created Air Guitar Hero as a fun rehabilitation exercise for people with amputations. Here we'll show you how to make an inexpensive version so anyone can play *Guitar Hero* without pushing buttons. It uses an electrode cuff, a modified Wii guitar controller, and open source code.

MATERIALS & TOOLS

Total project cost is about $500–$1,500 (not including a computer), depending on whether you buy the electrode amplifiers or make your own.

Nintendo Wii video game console
***Guitar Hero III: Legends of Rock* video game, Wireless Bundle with Gibson Les Paul controller**
DB9 D-sub connector, female, solder type #B000I-21YX2 at amazon.com
RS-232 serial extension cable, DB9 male-to-female item #02711 from Cables To Go (cablestogo.com)
Laptop computer running Windows XP (32-bit version)
EMG electrodes, silver-silver chloride, bipolar (1 box) We use Duotrodes, item #6145 from Myotronics (myotronics.com). These are consumables each time you play; a box contains 135.
Button snap-connectors from any fabric store
Myoelectrode amplifiers (4–8) One per electrode pair. The more electrodes you use, the more accurately Air Guitar Hero can decode your finger motions. Commercial-grade research units from Otto Bock Healthcare and Liberating Technologies (#BE328) cost about $500 per amplifier channel. As a DIY alternative, check out the Open Myoelectric Signal Processor that's being developed by Open Prosthetics, with 16 channels of amplification for about $250 ($16 per channel!) at openprosthetics.wikispot.org and code.google.com/p/myopen.

The cheapest option is to make your own bio-instrumentation amplifiers from op-amp chips, as described on page 263 of *Medical Instrumentation: Application and Design* by John G. Webster and John William Clark (Wiley, 1998, ISBN 0471153680). This is how we build EMG amps for a robotics class Robert teaches, and it's also how MAKE Labs built and tested the Air Guitar Hero system; for instructions and Eagle circuit board layout files, go to makeprojects.com/v/29. This method costs only a few dollars for 4 channels.

You might also try using amp chips from Linear Technologies (linear.com) for about $4 per channel. We haven't tried these, but we'd look for a configurable gain of 1,000–10,000, high common mode rejection ratio (CMRR) for noise rejection, and a single chip package. The LT1167 looks promising.

Data acquisition board item #USB-1208FS from Measurement Computing (mccdaq.com). Used for data logging and analysis, it samples real-world signals (e.g., force, EMG) and sends them to a computer for processing.
USB video capture device We used a generic device, model number VC-211A, but any one that supports 640×480 or 720×480 NTSC should work.
Screwdrivers: Torx T-10, Phillips #0
Rotary tool, high-speed e.g. Dremel
Soldering iron and solder

Software:
Matlab version R2010b or newer, from MathWorks (mathworks.com)
Matlab Data Acquisition Toolbox from MathWorks
Matlab Signal Processing Toolbox from MathWorks
MiniVIE from the Myopen project (code.google.com/p/myopen/source/checkout)

Garry McLeod

ROCKING OUT HANDS FREE

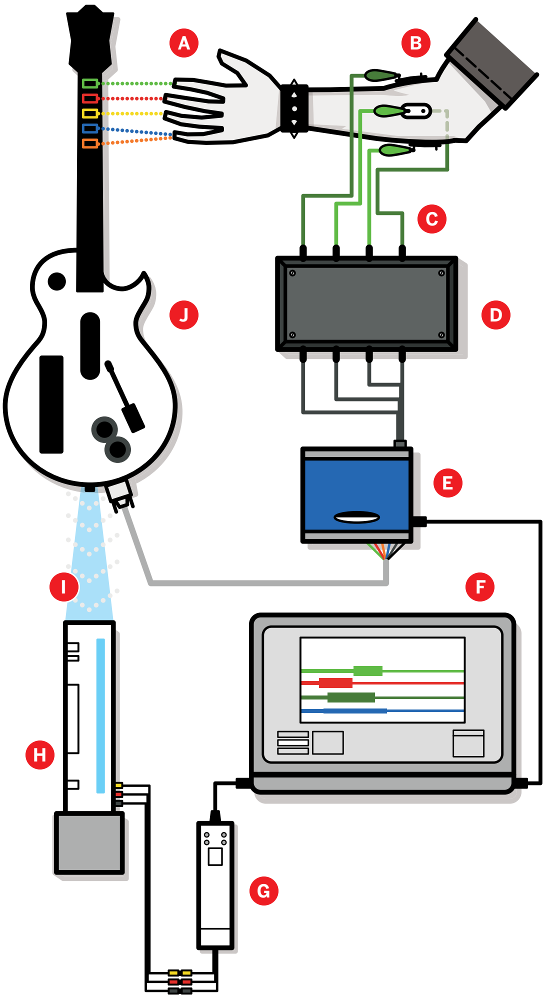
You play air guitar, moving your (A) **4 fingers** corresponding to the first 4 "note" buttons on the *Guitar Hero* controller.

(B) **Electrodes** on your arm detect tiny electrical signals from the muscles that move your fingers. These (C) **EMG signals** are boosted by (D) **amplifiers**, each on their own channel. The amplified signals are gathered by the (E) **data acquisition board**, which sends them on to the (F) **laptop computer**.

The (G) **USB video capture device** pulls the *Guitar Hero* video from the (H) **Wii video game console** into the computer, for purposes of training the software.

The (I) **Air Guitar Hero software** interprets the mixture of EMG signals as one of the 4 button-pressing motions, then sends the corresponding button command over to the (J) **hacked *GH* controller** which relays it to the Wii. It sends the Strum command automatically when you hit the note. You're rocking out!

NOTE: The hardest songs in *GH* require you to stretch your little finger to hit the fifth controller button. This motion is more difficult to train and decode, so it isn't used in this tutorial, but it's certainly possible to train the Air Guitar Hero system to recognize a fifth motion. Think of it as a challenge!



Wii-Hab Lab: How the Air Guitar Hero system works.

When a muscle contracts or flexes, it produces electrical activity. While faint (in the millivolt range), these signals can be detected by placing electrode sensors on the skin. The technology to measure, evaluate, and process muscular electricity is called *electromyography (EMG)*.

Air Guitar Hero uses EMG to send signals to the Wii console to control the game. But since the electrical signal generated by twiddling your fingers is very weak, additional computation must be performed to generate reliably accurate commands. The system uses pattern recognition algorithms to identify patterns in the EMG signals and decide which colored button to activate.

The algorithms require training data to provide examples of what signal characteristics to look for. First, you must correctly play on-screen notes with the guitar while the electrodes record your EMG signals.

Next, the recorded data is used to train a model for recognition the next time you make those movement patterns.

Third, practice makes perfect! Playing this type of video game can be useful for building muscle tone and dexterity.

Damien Scogin

1. MODIFY THE GUITAR CONTROLLER.

Our system needs to send computer-generated commands to the game console. We do this by sending digital output commands from the USB-1208FS data acquisition board. Our quick-and-dirty approach is to modify the guitar controller and override the manual buttons you'd normally press.

Make sure your Wii Remote is disconnected from the guitar controller. Unlock and remove the guitar neck and the front faceplate. Remove the four #0 screws on the front of the guitar and the eight T-10 Torx screws on the back of the guitar to open the controller. (Don't forget the gratifying removal of the "Void Warranty" sticker to get to the last Torx screw).

Using a Dremel tool, bore out a small D-shaped hole to fit the DB9 solder pot connector (circled in Figure A). Score along the outline of the connector, incrementally removing material and checking fit with the connector. Be sure to leave enough material on the sides of the connector for the mounting screws.

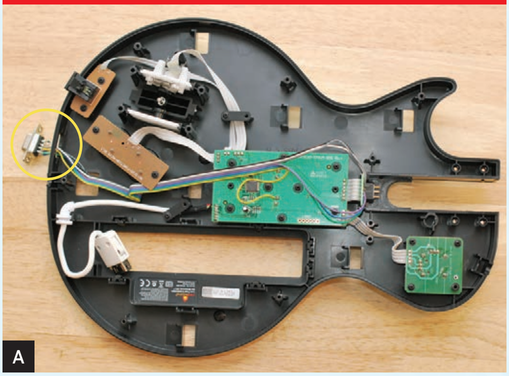
Once the connector fits, score the center location of the mounting screws, drill tiny pilot holes, and insert 2 small screws (or use 2 of the 8 Torx screws you removed), ensuring that everything fits (Figure B).

Remove the solder pot connector for wiring. Add seven 12" leads to solder pot pins 1–7 (one ground, plus 5 note buttons, plus the Strum button). Connect pins 1–6 to the 6 through-hole pads at the base of the guitar neck, from right to left if the push pins are on the bottom. Connect pin 7 to one of the Strum switch contacts; either Up or Down will suffice (Figure C). Ensure all wires are secure and close up the guitar.

Check your work! Use a multimeter to perform a continuity check between pin 1 (Ground) and each of pins 2–7 (Green, Red, Yellow, Blue, and Orange buttons, and Strum Up/Down). There should be no connection until each corresponding button is pressed.

Amy Bishop

TIME: 8 HOURS COMPLEXITY: DIFFICULT



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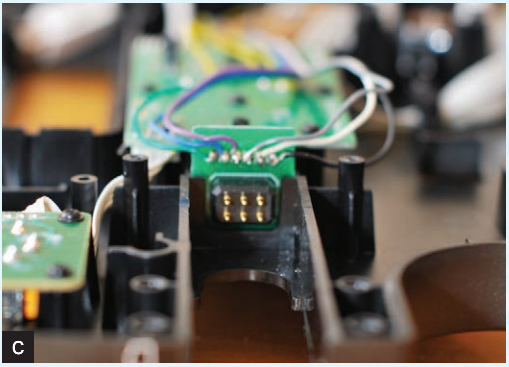

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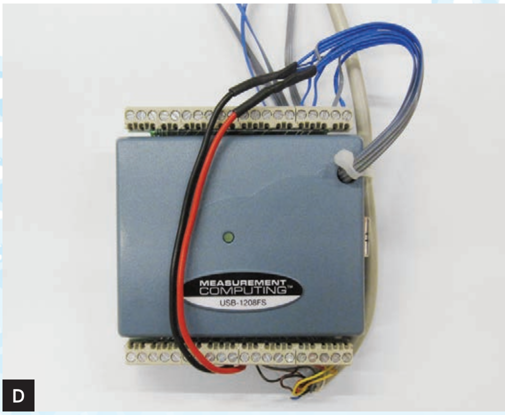
2. CONFIGURE THE DATA ACQUISITION BOARD.

Next, use a 3' section of serial cable and wire it to the digital I/O pins of the USB-1208FS data acquisition board. You only need half of the 6' serial cable, so cut off the male-pin half and use it to wire to the data acquisition board.

Connect pin 1 of the serial cable to terminal 29 (GND) of the data acquisition board. Connect pins 2–6 of the cable to digital ports



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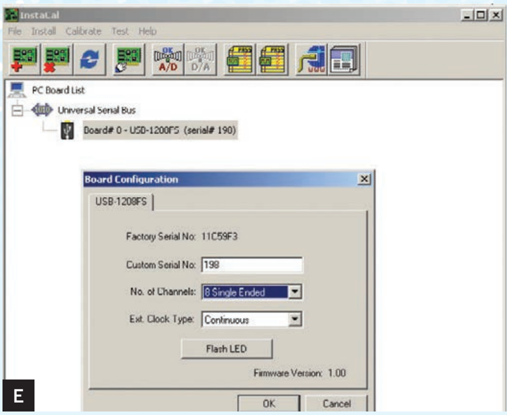


E

A0–A4 (terminals 21–25) respectively, and pin 7 of the cable to digital port A7 (terminal 28), as shown in Figure D.

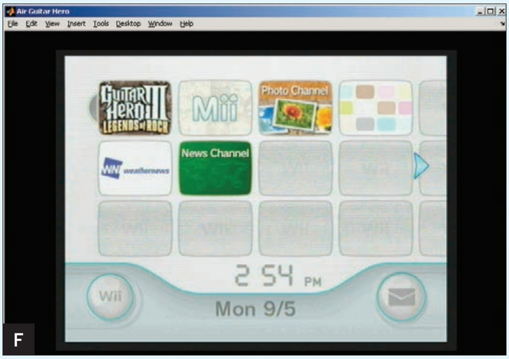
3. VERIFY COMPUTER CONTROL OF THE GAME.

At this point, a good intermediate checkpoint is to connect the data acquisition device and test *Guitar Hero* in Auto-Play mode. By routing the video signal to your PC, Matlab can detect each oncoming note from the game and then automatically send the digital signal to play that note for you. The software looks for the bright pixel intensities above the fretboard within *Guitar Hero* and then plays the corresponding note. (This is especially useful if there's a song in Expert mode that you just can't beat!)

Connect the USB video capture device to the Wii and to your computer, and install the drivers on your computer. This will allow the game to run on your PC.

Optional: Download and install Audacity (audacity.sourceforge.net) to allow "Software Play-through" of the game's audio channels through your laptop speakers.

Attach the USB-1208FS to your computer and install the drivers from makezine.com/go/usb-data. Once the drivers are installed, open the configuration utility (Start → All Programs → Measurement Computing → InstaCal), and ensure that the device appears in the list of detected PC boards (Figure E) and that it's configured for 8 single-ended analog inputs



F

(as opposed to 4 differential inputs).

Download the MiniVIE package from the Subversion repository at makezine.com/go/minivie. This is a package library based on the Johns Hopkins University Applied Physics Laboratory Virtual Integration Environment (JHU/APL VIE). It has a basic signal simulator that you'll use to test the functionality of your modified guitar controller.

Open Matlab and navigate to the MiniVIE directory. Type the following commands at the Matlab prompt:

```
>> MiniVIE.configurePath
>> Presentation.AirGuitarHero.AGH
```

The Wii console will display on your PC within Matlab (Figure F). Use the guitar controller to select and start the game. Once the song begins, click Auto-Play. The MiniVIE will graphically detect notes and then play them using the digital output pins automatically!

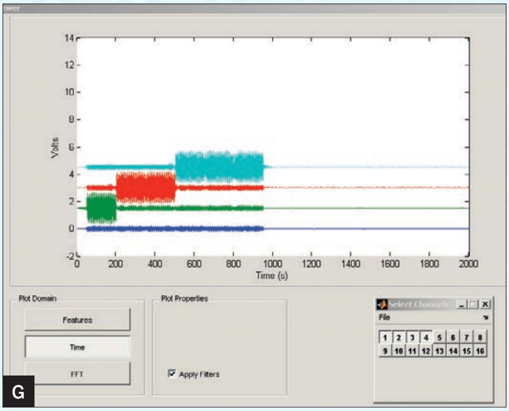
Robert Armiger / Carol Reiley

4. TRAIN THE PATTERN RECOGNITION SYSTEM.

Before you hook up electrodes and do anything with the EMG signal, it's worthwhile to get a feel for how the system operates. This can be done with the EMG Signal Simulator that's built into the MiniVIE system. You'll use the simulator to walk through each step of acquiring, processing, classifying, and displaying signal outputs.

Start the MiniVIE by typing in Matlab:

```
>> MiniVIE
```



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In the user interface that appears, select the EMG Simulator from the Inputs drop-down dialog. A small window will pop up in the bottom left side of the screen. When the window is selected, typing keyboard keys `a`, `s`, `d`, `f`, etc., will generate simulated signals as if a real DAQ system was present and connected to electrodes.

Preview the signal patterns by selecting the SignalViewer button. Each time a valid key (`a`, `s`, `d`, `f`) is pressed in the Signal Simulator window, a new pattern of simulated EMG activity will appear on the screen (Figure G). Typically one of the selected channels will get "noisier" in both frequency and amplitude for a selected pattern.

Next, choose linear discriminant analysis (LDA) as the pattern recognition algorithm to use for decoding signals by selecting LDA Classifier from the Signal Analysis drop-down menu. The classifier will be used in the following steps to attempt to recognize patterns from the input signals and label them as one of several discrete classes. Click on Select Channels and select Index, Middle, Ring, Little, and No Movement as the classifier's available choices.

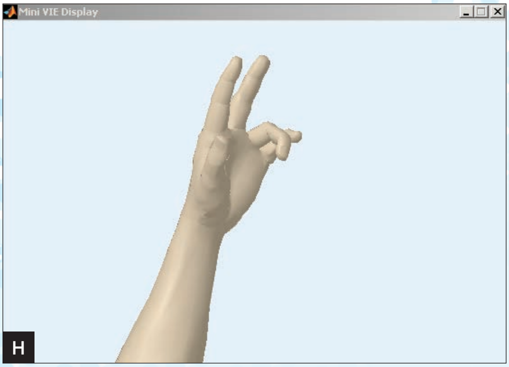
To use this pattern classifier, you need to create a training data set. From the Training drop-down menu, select Simple Trainer. Click the Begin Training button and a series of prompts will begin asking you to perform each of the movements you selected for the classifier (i.e. Index, Middle, Ring, Little). Each prompt begins by displaying the current class as text while a red bar moves from left to right. When the bar turns green (or slightly before), recording begins and you should perform the requested motion. In this case, while the green bar indicates data is recording, press the `f` key with your index finger. When the next prompt appears for Middle, press the `d` key, then `s` during Ring, and finally `a` during Little. In each case you're indicating to the software to generate the EMG pattern that will appear once you attach real electrodes.

After completion, you can save your training data in the dialog that appears.

Resulting accuracy is displayed in the console window. For example:

```
Training LDA with 551 Samples
(1=105; 2=109; 3=111; 4=112; 5=114;)
Percent correctly classified: 100.0%
Index Class accuracy: 100.0%
Middle Class accuracy: 100.0%
Ring Class accuracy: 100.0%
Little Class accuracy: 100.0%
No Movement Class accuracy: 100.0%
```

Once the training set has been created and the pattern recognition algorithm has been trained with output data, you can visualize these effects in a number of ways. From the Presentation drop-down menu, select the MiniV visualization utility. Pressing the keys



H

I

`a`, `s`, `d`, and `f` will cause the system to recognize simulated finger contraction patterns and display the corresponding finger movement in the visualization (Figure H).

5. ACQUIRE EMG SIGNALS FROM FINGER MOVEMENT.

Air Guitar Hero processes electromyogram (EMG) signals to decode your finger movements. To acquire these signals, you'll connect the input side of the electrodes to your arm via stick-on electrodes and a snap connector.

The EMG signal is a high-frequency white noise signal of several millivolts, with the most frequency energy in the 100Hz–400Hz range. The amplifiers act as an instrumentation (differential) amplifier with a variable gain (approximately 1,000x), which rejects common-mode signal (e.g., the 60Hz line noise coupled into our bodies) and amplifies local biopotential differences caused by muscle contractions (i.e., the EMG signal).

The USB-1208FS data acquisition system has a +5V power connection that can be used to power the electrode amplifiers.

The Otto Bock electrode amplifiers have 2 wires plus a shield on the input side (skin-side, unamplified), and 3 wires on the output side (amplified): +5V (power), ground, and signal. The output signal is centered at 1.2V.

If you build the electocardiogram (ECG) circuit from the schematic in *Medical Instrumentation: Application and Design*, note that its voltage and frequency ranges are slightly different than EMG amplifiers. EMG amplifiers have wider frequency response than ECG amplifiers, but do not cover so low a frequency range. The EMG amplifier must have higher gain than the ECG amplifier for the same output-signal range.

Disconnect your laptop from the wall supply. Although there's minimal risk here, with electrodes attached directly to your skin it's best to take every precaution to ensure you're isolated from any power fault your building might experience. This also helps to ensure that line noise isn't coupled into the data acquisition board.

Solder 2 snap-connectors to the input end of each electrode amplifier. Additionally, solder a third female snap-connector to the ground shield of one of the electrode amplifiers (Figure I).

Connect all the electrode amplifier output ground wires to the data acquisition board's digital ground (terminal 31) and all the electrode power wires to the board's +5V (terminal 30). Connect electrode signal outputs individually to analog input channels CH0–CH3.

Apply stick-on electrodes equally spaced around your forearm, about 1" below your elbow. Place the stick-on ground somewhere in the middle of your arm about 1" away from other electrode contacts. Snap on each amplifier lead wire to the electrodes.

Start the MiniVIE program again by entering `>> MiniVIE` at the Matlab command prompt. In the pop-up GUI, select DaqHwDevice from the drop-down menu, then press the Signal Viewer button to preview and display the signals (Figure J).

Verify that the signals displayed correspond to the contraction of your forearm muscles by moving your wrist and pinching each of your Index, Middle, Ring, and Little fingers.

6. ROCK OUT.

Once you've tested the individual components, it's time to put it all together to check out your Air Guitar Hero chops.

Disconnect your laptop from the wall supply. Ensure that the EMG electrodes are well attached to your forearm (too much electrode gel on the adhesive can make them fall off).

Open MiniVIE and select your input hardware device. Use the Signal Viewer to verify that the muscle signals are at rest when you're at rest; you should only see EMG activity when you're actively pinching your fingers.

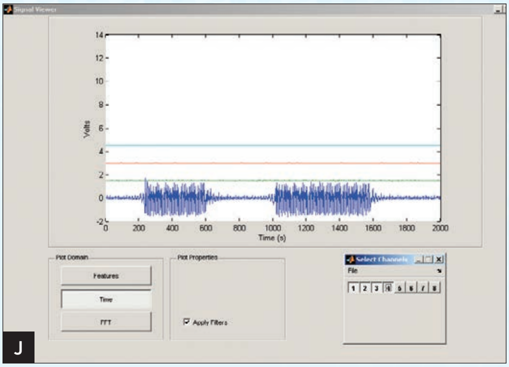
Select the LDA classifier and choose Index, Middle, Ring, and No Movement, initially for beginner mode. Train each of these classes using the Simple Trainer interface. Verify that your accuracy is at least 80% or higher.

Start your Wii console and select a song to play using the guitar controller, then select AGH from the Presentation drop-down and run it. In the default configuration, you don't have to use the Strum button. Just press your fingers when it's time to play the note, and it will be played with a strum added (Figure K).

That's it! Now you can play *Guitar Hero* simply by making muscle contractions and thinking about playing the desired note (Figure L).

And after you become a Rock God, you can modify your Wiimote — see our WiiEMG hack at makezine.com/go/wiiemg — to play games like *Wii Sports Tennis* or *Mario Kart*!

We'd like to thank Jonathan Kuniholm, founder of openprosthetics.org and Duke University doctoral candidate, and Jacob Vogelstein of the Johns Hopkins University Applied Physics Laboratory for their help creating and testing the first Air Guitar Hero system back in 2007.



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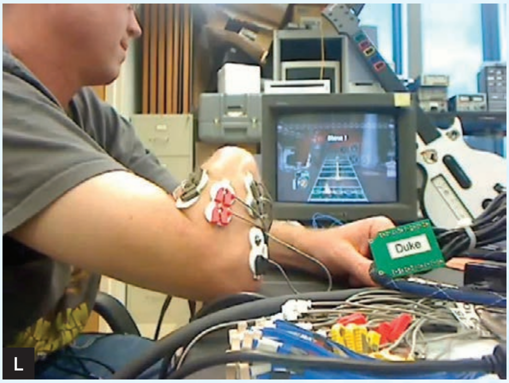

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See video of Air Guitar Hero in action at makeprojects.com/v/29.

Robert Armiger is an engineer at the Johns Hopkins University Applied Physics Lab working on the Revolutionizing Prosthetics Project. He completed his master's in biomechanical engineering at Johns Hopkins and his B.S. at Virginia Tech.

Carol Reiley is a surgical roboticist completing her doctorate at Johns Hopkins and running Tinkerbelle Labs.

PULSE SENSOR

A wearable device to give your projects a live heartbeat.

BY YURY GITMAN AND JOEL MURPHY

Poets and artists have always sought to bare their hearts to the world, and today heartbeat monitoring is essential to physicians, athletes, and many others. The beating of our hearts carries evocative power, symbolic meaning, musicality, and practical utility, so it's not surprising that many DIYers try to incorporate it into their projects.

Matt Richardson

Colleagues at Parsons The New School for Design, Yury Gitman is a toy inventor and product designer who teaches Physical Computing and Toy Design, and Joel Murphy is an artist and engineer who teaches Physical Computing and Cybernetics.

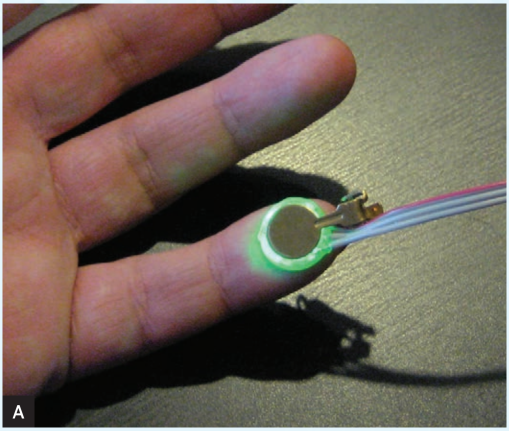
THE MOST COMFORTABLE AND WEARABLE technique for capturing heartbeats is to use an optical pulse sensor (Figure A). These devices shine light through the skin and then analyze the light reflected back — like shining a flashlight through your fingers to see your pulse. With each pump of the heart, capillary tissue fills with blood, increasing the tissue's volume and decreasing its reflectivity. Track the level of the reflected light with an optical sensor, and you can derive the pulse. (Oxygenated blood entering capillaries is more reflective at some wavelengths than the exiting "used" blood, but heartbeats still lower the overall reflectivity.)

Optical pulse sensors are easy to understand in theory, but in practice, it's hard to make one that works. As professors, year after year, we see our students attempt to follow published guides and either fail to get anything operational, or else get poor results. The circuit designs are typically too complex for novices; it's difficult building them to hold up to the physical stresses of being worn out in the world; and it's tough to program a microcontroller to extract a heartbeat from the raw and possibly noisy sensor data.

We decided to design a pulse sensor for small-scale manufacture that would be easy to use in our own creative projects, and that we could also make available to students, makers, game developers, mobile developers, artists, athletic trainers, and others. We knew about mobile apps like Azumio's Instant Heart Rate, which uses a smartphone's illuminator and ambient light sensor to read a pulse, but we wanted a simple, dedicated sensor that could be easily wearable, good for teaching, and "plug and play" into Arduino and other microcontrollers.

HARDWARE AND DESIGN

After months of experimentation with different optical sensors and LEDs, we hit on a good combination: a green LED from Kingbright (AM2520ZGC09) with a peak wavelength of 515nm, and a photosensor



A

Yury Gitman

MATERIALS

Pulse Sensor Kit pulsesensor.com, $20
Arduino-based microcontroller To make the Beating Heart Headband, use the MintDuino kit, listed below.

For the Beating Heart Headband, add:
Open Heart Kit MKJR1 from Maker Shed (makershed.com)
Mintronics MintDuino kit MSTIN3 from Maker Shed
Perf board, with at least 15×20 holes 276-149A from RadioShack (radioshack.com)
LilyPad LiPower power board DEV-08786 from Sparkfun Electronics (sparkfun.com)
Polymer lithium-ion battery, 3.7V, 850mAh, with JST connector PRT-00341 from SparkFun
Wire, insulated, 20–22 gauge
Header, male, right-angle, 3-pin
Fabric trim, at least 1¾" wide or other good material for a headband
Fabric or ribbon for headband lining
Snaps, small (4)
Thread
Cord elastic

TOOLS

Hot glue gun and glue
FTDI Friend and USB cable or FTDI-USB cable for programming ATmega328P chip in MintDuino kit
Computer with internet connection and USB port

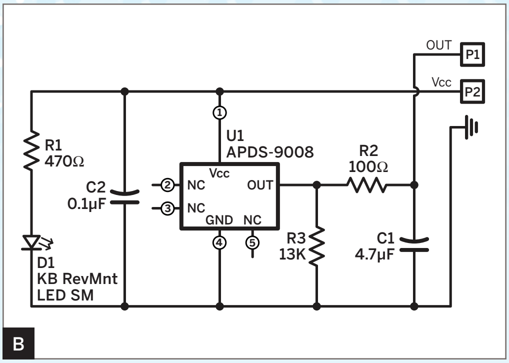
For the Beating Heart Headband, add:
Soldering equipment
Panavise
Tin snips, razor saw or other way to cut perf board
File
Wire cutters and strippers
Fabric shears
Sewing machine
Needle and pins

from Avago (APDS-9008) with peak sensitivity at 565nm. The sensor is designed for adjusting the LCD brightness of phones and laptops against ambient light, and it's only available as a surface-mount component. But it has its own integrated amplifier, which simplified the circuit we needed. Output from these sensors can be noisy, so we added a 100Ω resistor and a 4.7µF capacitor to act as a low-pass filter (Figure B). R3 sets the output sensitivity, and R1 sets the LED brightness. The other capacitor (C2) helps smooth the power supply.

Our final circuit uses just 7 components, and since they're all tiny surface-mount packages, the whole thing fits onto a ½" round PCB. The LED faces down into the board and the photosensor is surface-mount soldered right side up on the front, which lets them sit on the backs of flat panels. Fortunately for our needs, this also means that they send and receive light through holes drilled in the board, which isolates it against contamination from ambient light and lets the board lay flat and comfortably against the skin (Figure C).

Since production includes drilling holes in the board, we decided to add "buttonholes" around the outside of the sensor, to let users easily sew or attach it to various garments and fashion accessories. We ended up with a ½" green glowing disk that clips to an earlobe and resembles a prop from a science fiction movie. When we realized we had inadvertently made jewelry for a future race of human-machine cyborgs, we knew we were done.

On the software side, we wrote Arduino code that takes analog input from the Pulse Sensor, cleans up the signal, and outputs beat pulses to 2 output pins — a simple square wave to pin 13 and a pulse-width-modulation (PWM) fading pulse to pin 11 — for a more lifelike LED effect. The Arduino also continuously outputs current peak, trough, and beats-per-minute (BPM) values for the sensed waveform to its serial interface (ASCII via pins 0 and 1). Meanwhile, we also wrote a Pulse Sensor Visualizer in Processing that



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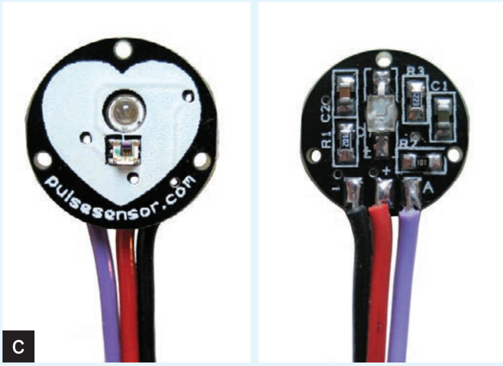

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you can run on a computer to read serial data from the Pulse Sensor and graph it on-screen.

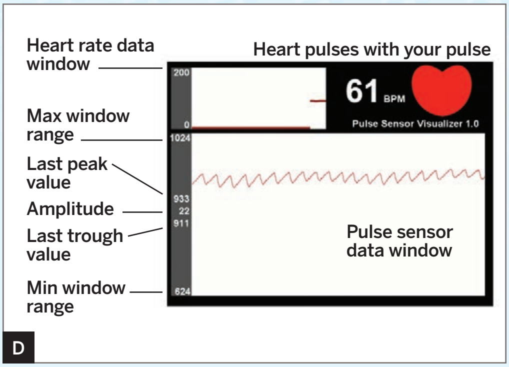
1. GRAPH YOUR PULSE

The best way to get started is to graph your pulse using the visualizer program. First, attach the clear sticker to the Pulse Sensor's face (logo side) to protect it from finger oils and sweat which could create a noisy signal.

Connect the sensor's standard 3-wire connector end to an Arduino board so the red wire runs to power (the Pulse Sensor works with either 5V or 3.3V DC), the black wire runs to ground (GND), and the purple wire (signal) runs to the Arduino's analog pin 5, which is set in the code as the `PulseSensor` pin. You can make the connections using jumper wires (Figure F) or a 3-pin header in a breadboard.

Before you attach the Pulse Sensor to the ear clip or velcro dot, get it up and running so you can find the best place on your body to get a good signal. If you don't already have

Damien Scogin (B)



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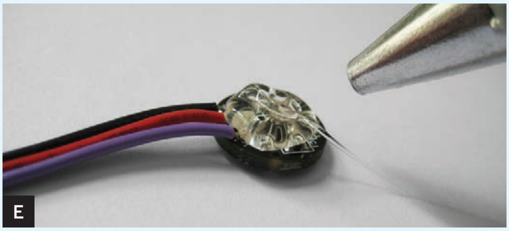
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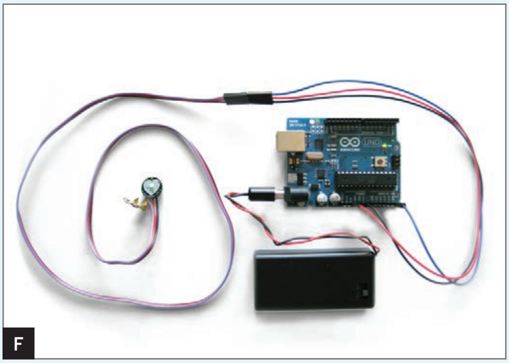
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them, download the Arduino and Processing programming environments at arduino.cc and processing.org, then download the latest Pulse Sensor software at pulsesensor.com.

Connect the Arduino to your computer and configure the Arduino IDE under the Tools menu for your specific board and the COM port it's plugged into. Open the *A_PulseSensor_XX* sketch (*XX* is the version number) and click Verify and then Upload to transfer it to the Arduino. You should see pin 13 blink in time with your heartbeat when you hold the sensor on your fingertip with the right pressure. There's a "sweet spot": too hard, and you squeeze the blood out of your fingertip; too loose, and you admit noise from movement and ambient light.

Play around and try different parts and pressures. Note that the Pulse Sensor has a warm-up period of up to 10 seconds, during which its signal is smaller. If you see an intermittent blink, or no blink, you might be a zombie or a robot.

Start up Processing on your computer, and run the *P_PulseSensor_XX* sketch. You should see a window showing a reconstruction of the raw waveform at the bottom (Figure D). Top center shows the current detected heart rate, top left charts it over time, and the red heart at top right pulses to the beat. If not, try other spots on your body; for example, Yury gets a clear, reliable signal when the edge of the sensor PCB is at the bottom edge of his earlobe.

2. PREPARE TO WEAR

Once you've found a good spot to wear the sensor, encase the components on the back in a layer of hot glue to prevent short-circuits (Figure E). If you'll wear the sensor on your finger, peel and attach one of the velcro dots over the hot glue, for attaching inside a velcro finger cuff. For wearing the sensor on your ear, press the back of the ear clip into the hot glue. The plastic body of the LED will prevent the metal clip from making any short circuits. If you make a mistake with hot glue, you can always reheat and rework it. You're done!

We've made some great projects with our Pulse Sensor, including a pulse-blinking heart-shaped pillow. And with 2 sensors, it's fun for a couple of people to try making their hearts beat in sync by controlling their breath or holding hands. Technology can get a bad rap for alienating people, but games with heartbeats bring people together.

Our friends Becky Stern and Jimmie Rodgers recently made a cute LED beating heart headband using the sensor and Jimmies' Open Heart kit. Learn how on the following page — take it away, Becky and Jimmie!

PROJECT: BEATING HEART HEADBAND

BY BECKY STERN AND JIMMIE RODGERS

THE OPEN HEART LED KIT BEGS TO BE controlled by a Pulse Sensor, and a headband makes a great location since it has easy ear-lobe access. First assemble the Open Heart Kit using the straight 6-pin header.

Refer to the MintDuino instructions to fit the ATmega328P chip and other components for an Arduino clone onto your perf board, cut to be smaller than the Open Heart. Mark the component locations, but don't solder them in yet (Figure A). Run the programming header along an edge, for easy plugging in. Add a 3-pin right-angle header for the Pulse Sensor to connect to power, ground, and an analog input pin. Also mark a 6-pin row, positioned to plug into the Open Heart's input header, to wire to 6 digital I/O pins.

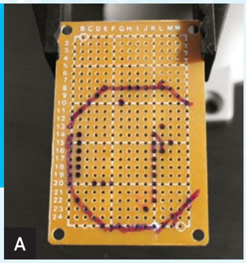
Cut the perf board to the same size as the Open Heart, file its edges, and solder on the Arduino components. Add V+ and GND wires, and connect the Pulse Sensor. Program the microcontroller (code is at the URL below), plug in the Open Heart, and test (Figure B).

Measure the circumference of your head, then cut 2 pieces of ribbon to that length. Line up the ribbons and use a zigzag stitch along 2" of the sides, tacking the ribbons together at the ends only. To make the headband stretchy, connect the ribbon tails by sewing them around a loop of cord elastic or a spare hair band. Adjust the amount of seam allowance so the headband fits snugly and comfortably (Figure C).

Decide where the Open Heart should go, and push its input pins through the fabric. Run the pins through their designated holes on the perf board Arduino, and solder into place, sandwiching the headband (Figure D).

Connect the power wires to the LiPower, and sew it into the headband near the heart (Figure E). Run the Pulse Sensor wires down the other side, and sew them in as far as needed for a good exit point near the ear (Figure F). The LiPo battery is small and light enough to not require sewing in. Finish sewing the lining and install snaps along one side to make a pouch for accessing the electronics. Switch on the LiPower, don the headband, and clip the sensor to your ear (Figure G)!

As a variant, we thought it would be interesting to replace the red LEDs with infrared. That way, the heart's blinking would not be visible to the human eye, but you could see it on camera. This would be a fun a device for a reality dating show, and any interested television producers are welcome to contact us.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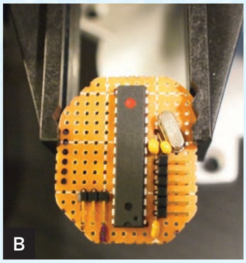
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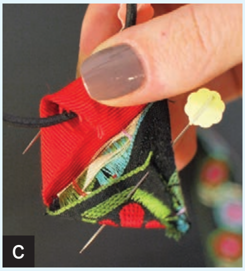
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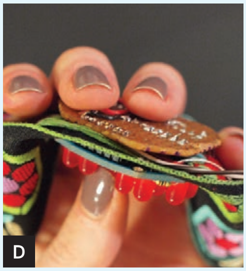
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G

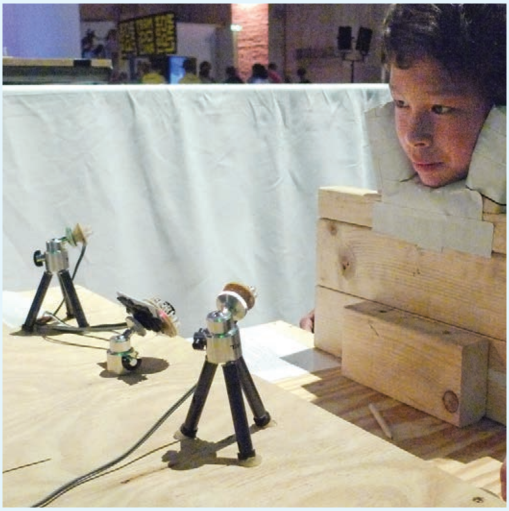
Jimmie Rodgers (A); Becky Stern (B–F); Matt Richardson (G)

+ Code, circuit diagram, video, and more photos at makeprojects.com/project/n/1622.

Becky Stern (sternlab.org) is senior video producer for MAKE. Jimmie Rodgers (jimmieprodgers.com) is an open source electronics maker and full-time nomad.

GATEWAYS TO THE SOUL

Two systems, EyeWriter and Eyeboard, let people draw, write, and connect using only their eyes.



People at all ability levels can move their eyes, and here are two projects that turn these movements into useful control inputs.

The EyeWriter interprets an infrared-illuminated webcam image of the eyes, while Eyeboard picks up signals from medical electrodes on the face. The Eyeboard is less accurate and only detects horizontal movements, but is also cheaper and easier to build and integrate with microcontrollers or other circuitry. EyeWriter uses complex software to analyze the video, which makes it harder to interface with, but it can be configured (in Mac OS X) to control a mouse pointer for any application.

EYEWRITER

BY ZACH LIEBERMAN

IN 2003, MY FRIEND TONY, AKA GRAFFITI artist Tempt1, was diagnosed with ALS, a progressive disease that left him almost completely paralyzed except for his eyes. In order to help him continue to make his art, I collaborated with a group of software developers and hardware hackers, including members of Free Art and Technology (FAT), OpenFrameworks, and the Graffiti Research Lab, to make the EyeWriter (eyewriter.org), a low-cost, open source, eye-tracking system that would allow Tempt1 and other ALS patients to draw and control a computer using just their eyes.

Our goal was a super-cheap system that could be made by almost anyone, almost anywhere. There are commercial and research eye-tracking systems, but they're complex and expensive, ranging upwards of $10,000. We limited the EyeWriter's design to emphasize low cost and ease of construction over other aspects of performance.

DESIGN

The EyeWriter works by illuminating the user's eyes in a controlled way and analyzing a video image of his eye movements. For the camera, we chose a PlayStation Eye (aka PS3 Eye), a small $25 webcam sold as a game system accessory.

The PS3 Eye captures 640×480 NTSC video and can be modified for high sensitivity to infrared, which makes the camera a favorite of the multi-touch hacking community. The PS3 Eye then feeds its video via USB to a computer, where it's captured by the EyeWriter application built in C++ using openFrameworks (openframeworks.cc).

For our first EyeWriter, completed in 2009, we put the PS3 Eye camera in front of one eye, mounting it to an extension attached to the front of a pair of eyeglass frames. The software cropped the video image, boosted its contrast, and thresholded it to show just a black pupil dot against a white background.

Theo Watson

To increase this dark-pupil effect, we illuminated the eyeball with 2 near-infrared LEDs mounted near the camera.

The software located the pupil's coordinates in the webcam image, and used a map to associate this location with the spot where the drawing brush needs to be on the user's computer screen. To build the map, the user ran through a calibration routine where he moved his eyes to visually follow a sequence of dots appearing around the screen.

This 1.0 version was simple and it worked, but only as long as the user's eyes stayed stationary relative to the screen. Move the head, and it threw the calibration off. So we decided to build a 2.0 version that's a bit more complex but allows for more normal head movement.

EYEWRITER 2.0

In EyeWriter 2.0, the camera sits fixed just below the screen, rather than wearable on eyeglass frames. There are 3 infrared illuminators: a ring of 16 IR LEDs surrounding the camera's lens, and two 8-LED illuminators on either side of the screen. We hacked the PS3 Eye to tap its VSYNC signal and feed the electrical signal into an Arduino, which uses it to strobe the illuminators with each video frame, alternating between the center and both sides. With the center illuminator on, the IR bounces off the back of the eye and creates the same glowing "red eye" effect that you see in flash photography, but with the side illuminators on, the pupils appear dark. This lets the software locate pupil position as the part of the image that alternates between light and dark.

Each side illuminator creates a "glint" where its light bounces straight off the eyeball and into the camera. By tracking the glint locations on both sides, as well as the center of the pupil, the system can calculate eye orientations no matter where the head is or which way the face is turned.

My students at Parsons School of Design have modified the EyeWriter software so

EyeWriter Team (eyewriter.org)

that it can control the cursor at the operating system level, not just in the eye-drawing application. Along with any button or other click input, this turns EyeWriter into a general-purpose mouse/trackpad replacement. EyeWriter 2.0 costs less than $150 to make, and the system holds its own against systems more than 50 times its price.

EyeWriter has won awards and has been well received, but it isn't reaching nearly the number of people that it could benefit. I've heard from many who want an EyeWriter for someone they love, but for whom making one is still a high hurdle. So we have been collaborating with MakerBot Industries on a kit that would include 3D printed pieces and everything else you need to build an EyeWriter 2.0. We expect to make this kit available sometime in 2012.

The biggest challenge with the kit right now is sourcing the camera. We want one that's higher grade than the PS3 Eye, has the same kind of VSYNC output pin, isn't expensive, and doesn't require cracking open a plastic case and throwing it away along with 4 unused microphones. Suggestions are welcome.

+ See makeprojects.com/v/29 for how to build an EyeWriter 2.0.

Zachary Lieberman is an artist, researcher, and hacker dedicated to exploring new modes of expression and play. He teaches at Parsons The New School for Design and is one of the co-founders of openFrameworks, a C++ library for creative coding.

EYEBOARD

BY LUIS CRUZ

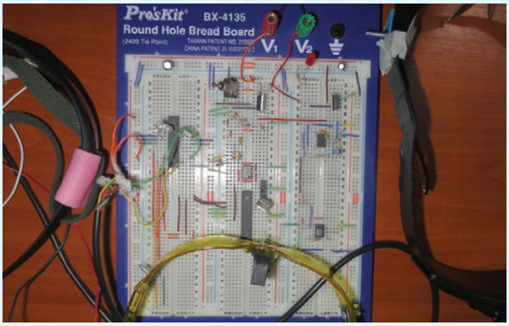
Luis Cruz

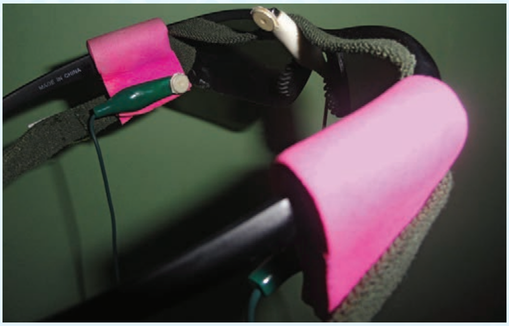
ONE OF MY HIGH SCHOOL CLASSMATES is quadriplegic, and from meeting him and hearing about others with similar conditions, I learned that many people with disabilities can't afford technologies that could enable them to communicate — especially in places like Honduras, where I live. The systems are way too expensive.

This motivated me to build an inexpensive yet reliable human-computer interface that detects eye movements using electrooculography (EOG), a biomedical technique based on picking up signals from electrodes placed around the eyes. EOG interfaces let users who can't manipulate a mouse or trackpad with their hands move a cursor on a computer screen. I knew that a cheap EOG system could be beneficial to many people.

DESIGN

The eyeball generates a voltage of 0.4mV–1.0mV (millivolts) between its cornea in front and retina in back. If you attach electrodes on opposite sides of the eye, they'll pick up some of this voltage, depending on where the eyeball is pointing. Looking straight ahead, with the cornea and retina equidistant between the electrodes, there will be no voltage. But with the eyeball angled to one side, you can measure a microvolt-level signal between the electrodes nearer the cornea and the one opposite. EOG can track both horizontal and vertical movements, but horizontal is easier and more useful. My system, like many others, only tracks horizontal using 3 electrodes: one right next to each eye, and the ground electrode centered on the





bridge of the nose or forehead.

A processor chip or even an oscilloscope cannot detect such small voltages, so the EOG system must amplify them, while also filtering out any noise from nearby electrical devices and wiring. You can see the circuit I built to accomplish this, along with step-by-step instructions for building my EOG system and programming its microcontroller chip, at makeprojects.com/v/29.

To amplify the signal initially, I use an INA118 instrumentation amplifier chip configured with a 100Ω resistor between pins 1 and 8, which gives it a gain of 501. The INA118 chip's high CMRR (common-mode rejection ratio) of 110dB eliminates common signals that go into both inputs, which removes some noise at the start of the signal path.

Noise from electrode circuits tends to come at high frequencies, so mine uses 2 passive low-pass filters in sequence, to reduce this noise above their cutoff frequency of around 16Hz. With the circuit I used, the formula for the cutoff is $1/2\pi RC$, where R is resistance and C is capacitance, so with a 100kΩ resistor and a 0.1µF cap, this comes out to 15.9Hz, which is fine; eye movements aren't so fast that filtering cuts out anything important.

Finally, a capacitor zeroes the signal by removing the DC offset added by the resting potential between the eyes, and a voltage follower circuit lets you connect a higher source impedance device than the EOG output's impedance, which is useful to connect an oscilloscope or multimeter for troubleshooting. To power the system, I use two 7805 voltage regulators wired in a trick way to supply the circuit with +5V, −5V, and ground (0V), eliminating the need for a dual power supply.

To process the amplified signal when the eyes move horizontally, I feed it into the analog-digital converter pin of an AT-mega328P microcontroller that's programmed to send the data to a computer via serial port. A Python script on the computer then sends the data to a C++ applet I wrote, which lets the user spell out messages. Looking to the left scrolls down through letters, and looking to the right selects them. To make wearing the electrodes more comfortable, I mounted them to some glasses modded with a headband and super glue. I've built several prototypes of these EOG glasses with good results.

I'm still improving this EOG system, including looking for ways to make it more comfortable to wear. I'm pleased to have developed a system for less than $200 that enables disabled people, like my classmate, to communicate, when commercial versions of the same cost a minimum of $10,000. I'd also like to create inexpensive EOG-interface systems for other applications, such as controlling a wheelchair or a television. I just graduated from high school, and what I need most of all in order to pursue these ideas is a scholarship, sponsor, or other funding source so that I can study electrical engineering in the United States.

Luis Cruz is an 18-year-old developer in Honduras who wants to pursue electronics engineering and contribute to the advancement of technology. For videos, downloads, and more info about this and other projects, or to donate to his college education and research, visit intelsath.com.

SEE INSIDE YOUR OWN EYES

The Shadowscope, the Transilluminator, the Light Swirler, and the Brain Scanner give you a personal glimpse into your own eyes.

BY MICHAEL MAUSER

Michael Mauser

Michael Mauser (michaelwmauser@gmail.com) is a retired engineer and science teacher who currently volunteers in the Expedition Health lab of the Denver Museum of Nature and Science. His interests in biology, physics, and psychology led him to develop numerous activities related to the five senses, which he hopes to publish soon as a book.

Researchers use sophisticated instruments to see inside our eyes, but techniques using simpler components have been in use for over 100 years. We'll use modern materials to re-create them. With these 4 devices you'll be able to see blood vessels, floaters, retinal surface tissue, nerve activity on your retina, corneal tears and wrinkles, lens features, and more.

THE SHADOWSCOPE

The Shadowscope uses a bright point source of light positioned close to the eye to cast shadows on the retina, revealing features on and in the eye. This technique was used as far back as 1760, and there are several ways of performing it.

The easiest way is to make a small hole in a card or piece of thin metal and hold it close to your eye while looking up at a bright sky or other featureless, bright background. Early experimenters also used a tiny drop of mercury on a piece of black velvet illuminated by a bright light, or they used a magnifying lens to bring the image of a distant point source of light close to the eye.

In the mid-1800s, the French inventor and performer Jean Eugène Robert-Houdin made an opaque cup that fit over the eye and had a tiny hole in it. In more recent times, Edmund Scientific sold a device they called the Eyescope, which used a ≤10mil (≤0.25mm) diameter "optic fiber."

Our device, which I call the Shadowscope, will be modeled after the Eyescope, but it'll be a lot cheaper and just as effective.

A

Gregory Hayes

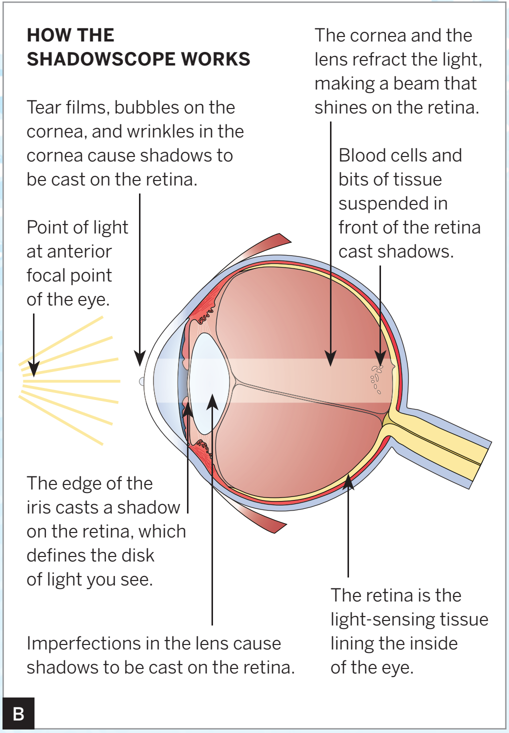
SHADOWSCOPE MATERIALS & TOOLS

Can, aluminum
Cellophane tape, matte finish
PVC tape, black (optional) aka electrical tape
Flashlight, AA Mini Maglite (optional)
Needle, sharp
Hammer, small
Safety glasses
Dremel with abrasive cut-off wheel (optional)

1. Cut a 45mm-diameter disk from an aluminum beverage can. Place the disk on a hard surface and make a small hole in the center by gently tapping a sharp needle with a small hammer until you can barely feel the tip sticking through.

You should see a tiny speck of light shining through when you hold the disk up to a very bright light. The smaller the hole, the sharper the images you'll see, just like with a pinhole camera.

2. Put a small piece of matte-finish cellophane tape over the hole to diffuse light. If you now hold this disk about 16mm in front of your eye (close enough that your eyelashes may brush it when you blink) and look toward a bright light, you should see a disk of light with shadowy features. You can use it this way, but I find it convenient to cut notches in the disk and use black PVC tape to mount it on a Mini Maglite flashlight as shown in Figure A.



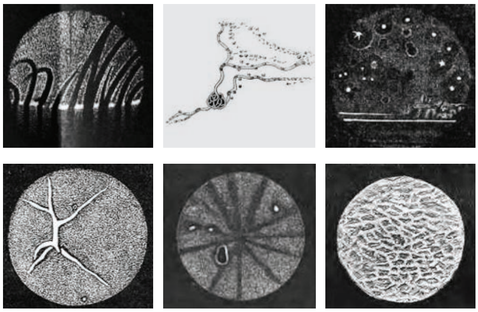


Fig. C: (clockwise from top left) Some features you may see with the Shadowscope are the shadow of upper eyelashes, floaters, bubbles and tear film on the cornea, wrinkles in the cornea, features associated with lens (2).

TRANSILLUMINATOR MATERIALS & TOOLS

LED, jumbo, super-bright, red RadioShack #276-0086 (radioshack.com)
Resistor, 68Ω
Flashlight, AA Mini Maglite
Soldering iron and solder

The disk of light you see when looking at the Shadowscope is actually the shadow your iris makes on the retina of your eye and not the image of the hole you made in the aluminum. You can make the size of this shadow change by looking toward a bright light with both eyes open and alternately covering one eye while holding the Shadowscope in front of the other eye. Figure B shows how the Shadowscope works and Figure C shows some of the things you may notice.

Hold your lower eyelid down with a finger and slowly blink your upper eyelid down. The shadow of your eyelid and eyelashes will be projected right side up on your retina, the light-sensing tissue at the back of your eye, but your mind sees the images on the retina reversed and upside down so it looks like your lower eyelashes.

Then move your eye from side to side to make the floaters move — these are bits of tissue and individual cells floating around in front of the retina.

Next, blink and squint to form spots and films on the surface of your eye, making shadows like those you see in the bottom of a pool on a sunny day. Anything that doesn't move is probably in the lens of your eye; this can vary greatly between eyes and people, as the 2 examples in Figure C show. Press gently on your eyelid over your cornea and you can make wrinkles that quickly fade, or squint hard and you can make a horizontal wrinkle.

THE TRANSILLUMINATOR

The Transilluminator (Figure D) is a bright light held on the side of the eye, which shines through the skin to light up the inside of the eye. This technique was described as far back as 1893, not long after practical incandescent lights were first produced. We'll use a much cooler LED to let you see the back of your own eye. (Note: This will only work well if you're light-skinned.)

1. Solder the resistor on one leg of the LED to limit the current to a safe level.

2. Cut the resistor lead and the remaining LED lead to the same length, and plug the assembly into the bulb socket of a AA Mini Maglite flashlight (you may have to rotate the assembly 180° to get the polarity right).

3. Stand in front of a mirror in a dimly lit room and hold the LED against the skin on the outside corner of your right eye while turning your gaze toward your nose. If you turn your head slightly to the right, you'll be able to use your left eye to see the pupil of your right eye glowing red in the mirror (see page 62). By changing the focus of your eyes, you may be able to see blood vessels magnified by the cornea and lens in the right eye. The largest of these vessels are about the size of a human hair.


D

THE LIGHT SWIRLER

The Light Swirler (Figure E) is a device for smoothly moving a bright light in your peripheral view to cast shadows of the blood vessels and tissue surfaces on top of your retina. Think of it as a kind of retinal scanner, revealing the unique pattern used in real retinal scanners for identification purposes. This technique was first described in 1819 using a handheld candle. Our device will be a scaled-down version of an instrument described in 1926, which used an incandescent bulb. Again, in our modern version, we'll use an LED.

You can get a preview of what you'll see with the Light Swirler by covering one eye and looking straight at a blank wall with the other eye while you rapidly flash a focused beam of light on the pupil from the side. Done correctly, you will see a branching pattern blinking on and off.

With the Light Swirler the view is considerably more dramatic and detailed — the shadows writhe around without the distracting blinking, and you can even see the moving shadow from the slight depression in the retina at the center of vision (the fovea) and the texture of the surface at the back of the eye.

To make it, you'll mount a small lazy Susan between a putty knife and a ceiling fan pan box so you can rotate the box from the back. The pan box will contain the LED, switch, and battery box.

LIGHT SWIRLER MATERIALS & TOOLS

PVC ceiling fan pan box and round cover
Bracket used in electrical boxes for supporting light fixtures
Lazy Susan, 3", square Rockler #28951 rockler.com
Putty knife, plastic, 4"
Battery holder, 2×AAA RadioShack #270-398 (radioshack.com)
Slide switch RadioShack #275-0406
LED, white RadioShack #276-0017
Nuts and screws, #6-32, 1" (3), ¼" (9–11)
Pipe strap (optional)
Paper
Tape, double-sided
Soldering iron and solder
Common hand tools
Drill
Hot glue gun and glue sticks
Dremel rotary tool with sanding drum and cutoff wheel (optional)


E

1. Start by making the crank arm. I used an electrical box bracket and a #6 screw and nut to make a crank as shown in Figure F. This

Gregory Hayes

was handy because the bracket already had 2 of the holes and also had bends started in the right spots. Alternatively, you could use stiff pipe strap or another source of metal.

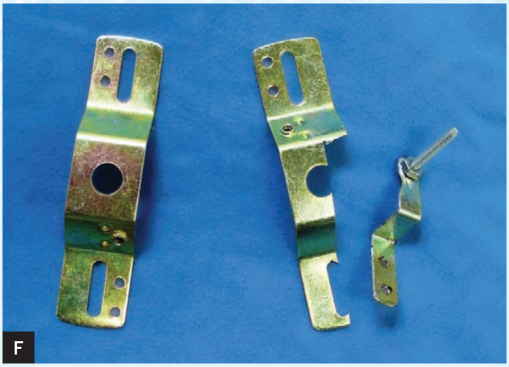
2. Mark holes in the pan box for mounting the crank and the lazy Susan, and mark trim areas and holes on the putty knife for the lazy Susan (Figure G). Drill holes, cut trim areas, and assemble with #6 screws and nuts. I used the Dremel sanding drum for all trimming. You can cut off the ends of the screws with a Dremel abrasive cutoff wheel.

3. Now that we have the rotating mechanism, we can work on the electrical part. Cut and sand down the protrusions on the outside of the fan box — I used the Dremel sanding drum. Glue the battery box inside the fan box. Bend the slide switch tabs in slightly, and cut and drill the box to allow it to be mounted as shown in Figure H. Drill a pair of holes in the side of the box for the LED and glue it in place with hot glue so it points up at about 45° (Figure I).

4. Wire the switch, battery box wires, and LED together, taking care to get the polarity right (the longer lead on the LED is positive and goes to the red wire). For added protection of the LED, you can add a bit of pipe strap, either as a hood or as a holder, as shown in Figure J. Additional hot melt glue can also be added around the LED.

5. Mount the fan box to the cover/lazy Susan assembly using two #6 screws and nuts. Use double-sided tape to stick a disk of paper to the box, and your completed Light Swirler should look like Figure E (previous page).

To operate the Light Swirler, turn on the LED, close one eye, and hold the assembly close to the other eye. Rotate or oscillate the light while looking straight ahead at the blank surface. You should try to hold the Light Swirler so that the light is visible at all times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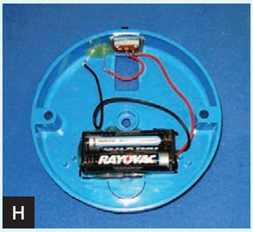

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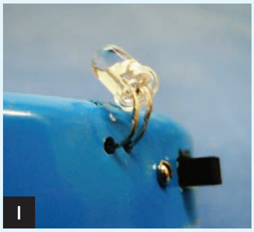
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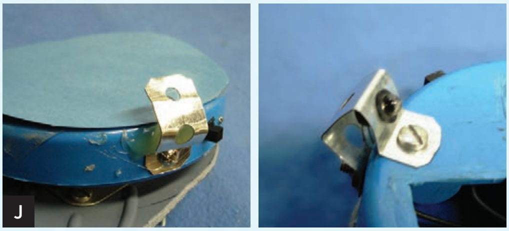

J

but never in your direct line of sight. The light is focused by your eye onto a part of the retina far from your center of vision. This results in what is essentially a bright light source within the eye itself, moving and shining on the blood vessels from a very oblique and unusual direction. The blood vessels lie a little above the light-sensing retina, and the moving light source never gives the retina time to compensate and cancel out the shadows.

The shadow image you see is unique to your

Michael Mauser

eye. A real retinal scanner works by measuring the reflectance from a beam of infrared light as it sweeps a circular path on the retina. The changes in reflection due to intercepted blood vessels result in a unique digital signature.

THE BRAIN SCANNER

The Brain Scanner (Figure K) allows you to see the nerve activity on your retina, and because your retina is considered part of your brain, you will actually be seeing your own brain activity. This effect was first reported in 1825 and is called "the blue arc phenomenon." It's a subtle effect but I consider it the most beautiful thing to see in your eye.

1. Cut a disk out of an aluminum beverage can to fit over the end of the paper towel tube, similar to how we made the Shadowscope.

2. Punch a small hole in the disk with an awl or the tip of a knife, and tape some red cellophane over the hole using matte-finish tape. Now tape the disk over the end of the cardboard tube as shown in Figure K.

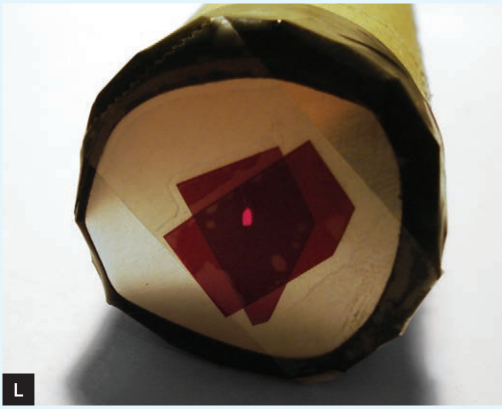
To use the Brain Scanner, hold it up to your right eye and line it up with a bright light source. Close both eyes for 30 seconds and then open the right eye and look to the right of the glowing red dot. You should see 2 blue arcs going from the red dot toward the right somewhat. They will fade after a few seconds, and if you look directly at the red dot they'll disappear.

It may take several tries to see this. Between tries you need to open your eyes, then close them again for 30 seconds to partially accommodate them to the dark. You can use your left eye, but you must then look to the left of the red dot, and the arcs will be to the left.

The arcs are due to the activity of the nerves that are carrying the signal from the photoreceptors responding to the image of the red dot on your retina. Your retina is actually an outgrowth of your brain, so you're seeing brain cell activity!

Gregory Hayes (K)


K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BRAIN SCANNER MATERIALS & TOOLS

Paper towel tube
Aluminum can
Cellophane, red
Cellophane tape, matte
Awl or knife

CONCLUSION

There's a lot of room for substitution and innovation on any of these projects — use your imagination and what you have available to save time and money.

For more information on floaters and the blue arcs, see the "Amateur Scientist" articles by Jearl Walker in the April 1982 and February 1984 issues of *Scientific American*. You can also view and download articles I wrote for *The Physics Teacher* and *The American Biology Teacher*, which describe these and other things you can see inside your eyes at makezine.com/go/mauser and makezine.com/go/mauser2.

NORTH PAW AND HEART SPARK

Sensebridge makes devices that let people feel direction and see their heartbeat.

BY JON KALISH

Sensebridge (sensebridge.net) is a maker of electronic kits geared toward personal hacking. It was started by a group of friends at the San Francisco hackerspace Noisebridge. Jon Kalish spoke with Sensebridge's Eric Boyd, who now lives in Toronto, about the company's first two products.

Jon Kalish: How does North Paw work?

Eric Boyd: It's a compass anklet. You strap it on and it basically vibrates to tell you which way is north. Inside the anklet are eight vibrating motors just like the one inside your cellphone. And they're spaced equally around your ankle. One of those motors is on at all times — it's a persistent stimulus.

No matter which way you're facing, it tells you where north is. That persistent sense of north is the most important thing about North Paw. Because of the plasticity of your brain, after a while it will stop telling you, "I'm feeling a buzzing on my ankle," and instead your brain will tell you, "North is that way." And that's the genius of the device, this idea that our brains can adapt over time to a persistent stimulus. It's really amazing.

JK: What do you see as the market for North Paw?

EB: As soon as we could strap working prototypes on our friends, people started telling us that they wanted them. They were like, "This is so cool. I want to be able to buy it. Are you going to sell kits?" Our market is the geek market and people who are really into hacking themselves.

But in the wider market there are so many people who claim they have no sense of direction. And this can totally fix that problem. You know when you come up out of the subway station and have no idea which way to go? The North Paw solves that problem. I think there's a market for it with outdoor enthusiasts, the military, firefighters — anybody who finds it kind of important to have situational awareness.

JK: So, tell me about Heart Spark.

EB: It's a pendant that you wear, and it flashes little lights in time with your heartbeat. You have to wear the type of chest strap used by runners and people who want to optimize their exercise experience. It detects your heartbeat using electrocardiogram technology, and transmits it wirelessly to the

pendant, which receives the signal and flashes the lights.

JK: Why did you come up with Heart Spark?

EB: I'm really interested in the implications of making that kind of personal biometric data totally visible. When you broadcast your heartbeat into a social situation, how does that change the way people behave? How does it make people feel about you?

I've had all kinds of very interesting social dynamics when I wear it, and that's one very interesting reason to wear it. It's a good way to start conversations. I can use the pendant to not only display the heartbeat data but to log it. Then I can go back later and look at the logs of my heartbeat to see what was happening over the course of the day. And that's just fascinating stuff.

Gregory Hayes

+ Order Sensebridge kits at sensebridge.com.

Manhattan-based radio reporter and podcast producer Jon Kalish can be reached at (212) 989-5619. For links to radio docs, podcasts, and DIY stories on NPR, visit jonkalish.tumblr.com.

DIY BLOOD PRESSURE MONITOR

Make a blood pressure tester that's tough, smart, and mobile.

BY ALEX RUSSELL, GARRICK ORCHARD, AND CAROL REILEY

High blood pressure, also called hypertension, is deadly: it can lead to heart failure, stroke, and kidney failure. One-third of Americans have it, and in the developing world it's the leading killer of pregnant women due to lack of screening.

Existing blood pressure tests are painless but the equipment is flawed: it's delicate and impractical in many settings, and it contains mercury, which is toxic when released into the environment. It's also prone to human error, because it depends on a doctor listening to the patient's pulse through a stethoscope.

So we came up with a DIY blood pressure monitor that's better. It's portable and battery-powered, making it great for areas with unreliable electricity. It's solid-state, so it's tough and reliable and doesn't contain mercury. And it detects high blood pressure automatically, drastically reducing error.

Here's how you can build one for less than $50 and test your blood pressure anytime.

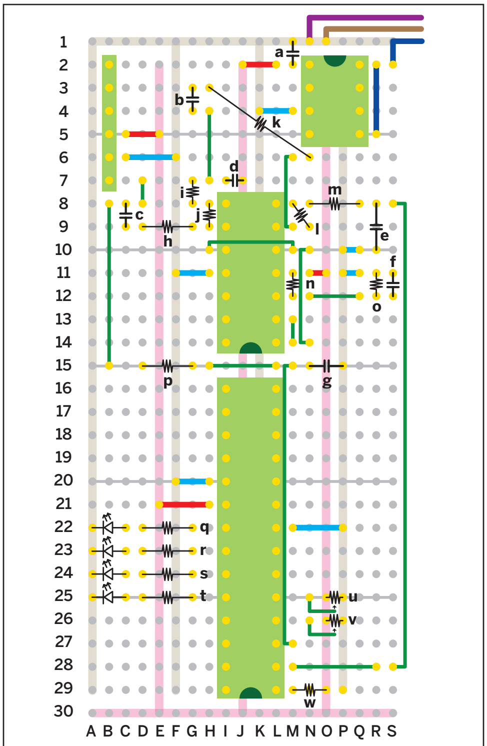
OUR DIY BPM

Our Self-powered, Environmental, Affordable Blood Pressure Monitor (SEA-BPM, or *sea-bump*) is easy to use. An inflatable arm cuff contains an electronic pressure sensor that measures the air pressure inside the cuff. When the cuff is inflated sufficiently it completely occludes the artery. As the cuff is deflated blood starts to flow through the artery, and pressure on the arterial walls rises and falls with every heartbeat.

This causes oscillations of the cuff's pressure that are detected by the sensor, and can be used to calculate both the systolic (maximum) and diastolic (minimum) blood pressures. This is known as the *oscillometric blood pressure method* (for details, see makezine.com/go/obpm). Our algorithm to calculate both pressures is implemented in C for programming onto a PIC microchip.

For energy efficiency in areas of the world without reliable electricity, our device uses NiCad batteries that are recharged using a hand crank generator. Fully charged, they power the device for about 50 hours. We also removed the delicate mechanical pressure meter from the device to reduce the size and

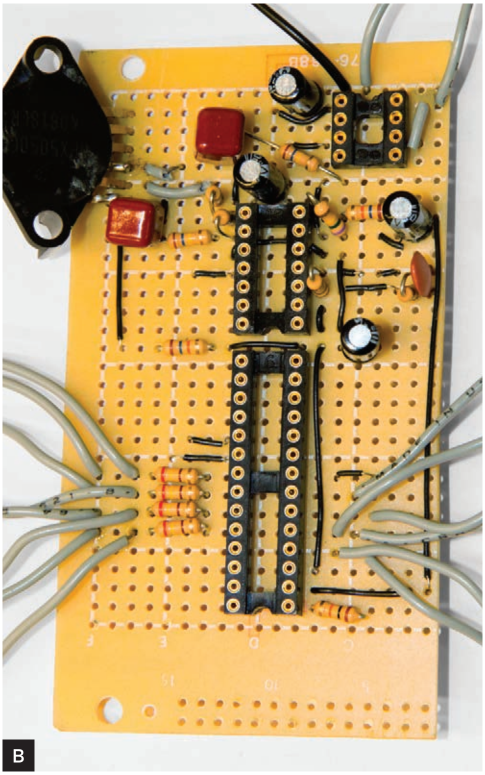
Garry McLeod



KEY
Pink: +3.3V
Gray: ground
Red: wire to power
Light blue: wire to ground
Green: wire
Purple: to battery ground
Brown: to crank ground
Dark blue: to switch

a. 1μF	m. 16kΩ
b. 1μF	n. 110kΩ
c. 1μF	o. 110kΩ
d. 1μF	p. 160kΩ
e. 1μF	q. 200Ω
f. 0.1μF	r. 200Ω
g. 1μF	s. 200Ω
h. 160kΩ	t. 200Ω
i. 16kΩ	u. 100kΩ pot
j. 750kΩ	v. 100kΩ pot
k. 160kΩ	w. 10kΩ
l. 750kΩ	

A



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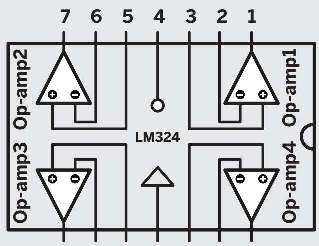
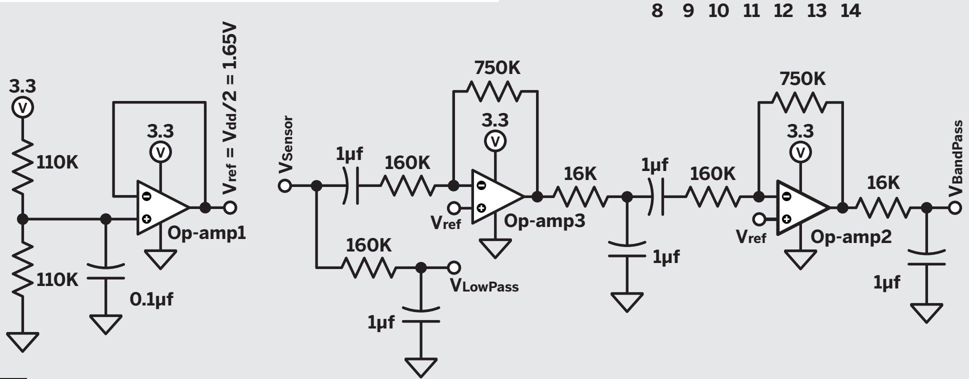




C

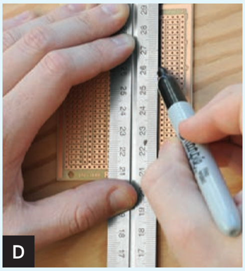
Garrick Orchard; Damien Scogin (C)

MATERIALS

Circuit board, about 3"×4" RadioShack part #276-168, radioshack.com
DIP sockets: 8-pin (1), 14-pin (1), and 28-pin (1) such as Digi-Key parts #A24807-ND, A24808-ND, and 3M5480-ND, digikey.com
Voltage regulator IC, 8-pin Digi-Key #LT1121CN8-3.3#PBF-ND
Microcontroller, Microchip PIC18F2321 Digi-Key #PIC18F2321-I/SP-ND. When you order, request that Digi-Key pre-program your PIC with the code at makeprojects.com/v/29. If you have your own PIC programmer, then you can do the programming yourself. Requires MPLAB and C18 compiler to build, or just program the hex file onto the device.
Op-amp IC, quad, LM324N package Digi-Key #LM324NFS-ND
Resistors: 110kΩ (2), 160kΩ (3), 16kΩ (2), 750kΩ (2), 10kΩ (1), 200Ω (4) You can use 240Ω resistors for the LEDs, but with 200Ω they'll be brighter.
Capacitors: 0.1μF(1), 1μF (6) Five of the 1μF capacitors must be non-electrolytic, because electrolytic caps can't be used for the high-pass filters. The 2 remaining caps, 1μF for the voltage regulator and 0.1μF to stabilize the voltage reference, can be electrolytic.
LEDs, 5mm: red (1), green (1), yellow (1), clear (1) RadioShack parts #276-209, 276-304, 276-021, 276-014
Pressure sensor, 5V, 7mA, 6-pin Mouser Electronics part #841-MPX5050GP1, mouser.com
Wagan Micro Dynamo LED Flashlight Charger Amazon part #B00198GFAG, to be disassembled for the hand crank. A cheaper hand crank can be used; they're about $2 in bulk from alibaba.com.
Battery holder, 3×AA Digi-Key #BC3AAW-ND
Batteries, NiCad, AA (3) Digi-Key #SY114-ND
Sphygmomanometer with nylon cuff pre-gauged for adult arm size 10"–16", Amazon #B000G35EP2
Project box, approx. 6"×4"×2" such as RadioShack #270-1806
Knobs, 1" (2) RadioShack #274-416
Potentiometers, 100kΩ, linear taper (2) RadioShack #271-092
Toggle switch, SPDT Digi-Key #450-1523-ND
Wire, insulated, 20–22 gauge, 24 gauge We recommend 24 gauge for the jumper on row 10 that goes under the DIP socket; 20–22 for everything else.

TOOLS

Saw
Marker
Soldering iron and solder
Wire cutter/stripper
Screwdrivers
Drill and drill bits: 3.5mm, 5mm, 6mm, 7.75mm, 8mm or whatever fits your LEDs, potentiometers, and switch
Hacksaw
Clamp
Label maker
File (optional)
PIC programmer (optional)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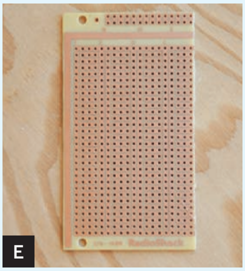
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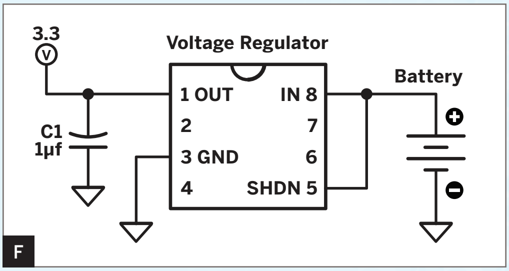


F

weight and make it more robust. Since it's automated, readings are more precise and not prone to human error. A reading takes less than 30 seconds.

1. BUILD THE CIRCUIT BOARD

1a. Cut the board to size.

With a black marker, mark the circuit board as shown, and cut it with a saw (Figures D and E).

1b. Add the voltage regulator.

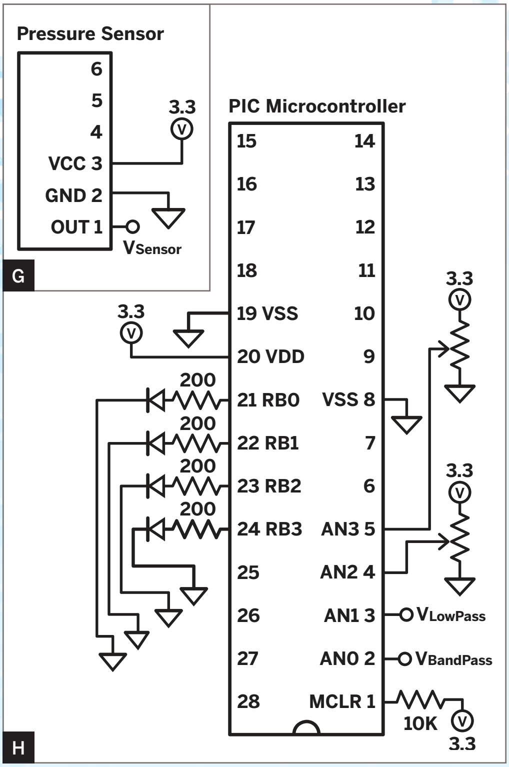
Place the 8-pin DIP socket into the upper right of the circuit board and solder the connections as shown in Figures A, B, and F.

Solder a 1μF capacitor between pin 1 and ground. Solder a wire from pin 8, to be connected later to the loose wire from the switch. Solder 2 wires to the circuit ground, for the crank ground wire and a battery ground wire.

1c. Add the filters.

Solder the 14-pin DIP socket onto the board as shown in Figures A–C and add wires for power: pin 4 goes to 3.3V and pin 11 goes to ground. If you use wire thicker than 22 gauge,

Gregory Hayes (D,E), Damien Scogin (F)



you may need a longer jumper on row 10 to go around the socket rather than under it.

Build a 1.65V reference voltage using op-amp 1 in the LM324 chip. Solder the two 110kΩ resistors and the 0.1µF capacitor as shown in Figure C. Connect op-amp 1's output to its own negative terminal.

Now add the smoothing filters and frequency components of the blood pressure sensor. The sensor's signal follows 2 forks: through a *band-pass filter* and a separate *low-pass filter*.

The band-pass filter consists of 2 high and low-pass filters, cascaded together. Make the first high-pass filter by soldering a 1µF capacitor in series with a 160kΩ resistor. Connect the cap to the pressure sensor's output pin 1, and the resistor to the negative input of op-amp 3. Add gain to the circuit by soldering a 750kΩ feedback resistor between op-amp 3's output and its negative terminal.

Follow this with a low-pass filter: solder a 16kΩ resistor from the output of op-amp 3 to an open hole on the project board, and solder a 1µF capacitor from this hole to ground.

Feed the output of the low-pass filter into a second high-pass filter made by placing a 1µF capacitor in series with a 160kΩ resistor.

Take the output of the second high-pass filter and feed it into the negative terminal of op-amp 2. Add gain to the circuit by soldering a 750kΩ resistor between op-amp 2's output and its negative terminal.

Take the output of the gain stage and wire it to the input of a second low-pass filter: solder a 16kΩ resistor from the output of op-amp 2 to an open terminal hole, then solder a 1µF capacitor from this hole to ground. Connect this filter's output (VBandPass) to the microcontroller's pin 2 (analog input 0).

Now wire the separate low-pass filter: a 160kΩ resistor from pressure sensor output pin 1 to an open hole, and a 1µF capacitor from this hole to ground. Connect this filter's output (VLowPass) to microcontroller pin 3 (analog input 1).

1d. Add the pressure sensor.

Solder the pressure sensor in the top left of the board and connect it as shown in Figures A, B, and G.

1e. Connect the microcontroller socket.

Solder the empty 28-pin DIP socket onto the project board as shown in Figures A and B, so its pin 1 is at the bottom. Wire the connections, following Figures A, B, and H, but don't plug in the microcontroller chip until you're done soldering.

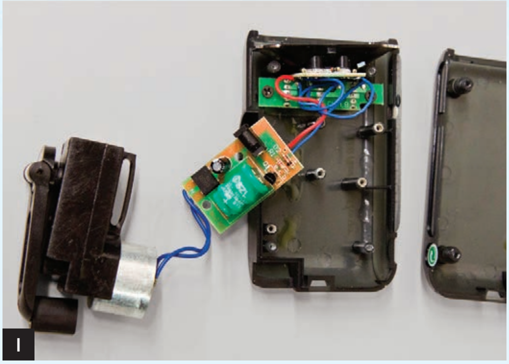
Wire the power terminals: pins 8 and 19 go to ground, pin 20 goes to +3.3V.

Wire the master clear (pin 1) to +3.3V via a 10kΩ pull-up resistor.

For the LEDs, solder four 200Ω resistors to pins 21–24 of the microcontroller as shown in Figures A, B, and H. Solder leads to the LEDs and back to ground, as shown. The LED order is: power (clear) on pin 21; status (yellow) pin 22; pass (green) pin 23; fail (red) pin 24.

Connect the pots as shown in Figures A, B, H, and K. If the soldering feels cramped,

Damien Scogin (G and H)



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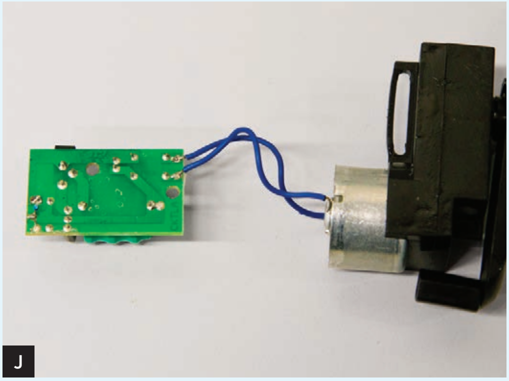

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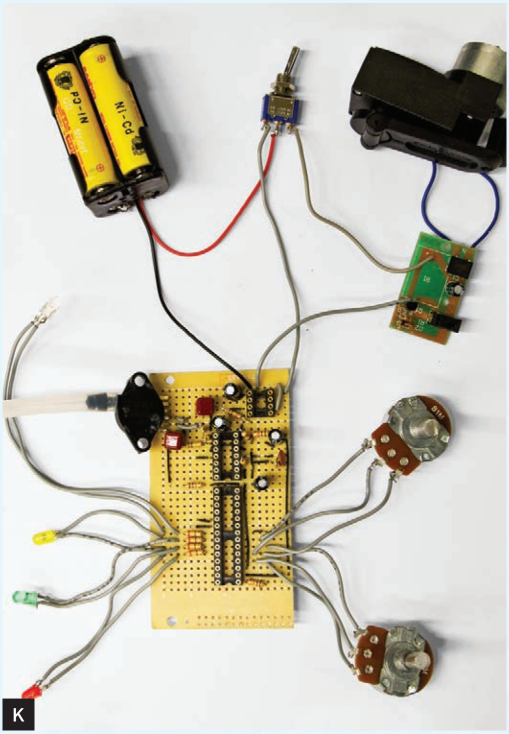


K

Garrick Orchard

you can use adjacent holes on the power and ground traces.

2. BUILD THE POWER SUPPLY

Now you're going to mod the flashlight charger to make your hand crank generator.

2a. Salvage the crank and its circuit board. Flip the flashlight over and remove the 4 screws located in the corners of the outer housing. Remove the outer housing.

Remove the screws holding the hand crank in place, then remove the screws holding the larger circuit board in place (Figure I).

Cut the wires running between the 2 circuit boards. You'll be left with the crank still connected to the larger board (Figure J).

2b. Unsolder the battery. Remove it from the board. You'll replace it later with 3 NiCads for longer life.

2c. Hook up the switch and new batteries. Solder a wire from the positive terminal of the crank circuit board (marked) to one of the switch's outer terminals.

Solder the positive wire from the battery holder to the middle terminal of the switch (Figure K). Insert the 3 NiCad batteries into the battery holder (4-battery holder shown here).

2d. Connect it to the project circuit board. Now connect the 2 loose wires you added in Step 1b: solder the wire from pin 8 on your voltage regulator to the remaining outer terminal of the switch, and solder your crank ground wire to the negative terminal of the crank circuit board (Figure K).

You now have a simple rechargeable power supply. In one switch position, batteries are connected to the crank and can be recharged. In the other position, batteries are connected to your circuit to provide power. This way, the crank is never directly linked to your circuit because that could cause damage.

3. BUILD THE BOX

3a. Drill the lid.

Drill 9 holes total, for the switch and LEDs across the top and the pots across the bottom, following the drilling diagram (Figure L).

3b. Test-fit the components.

Release the lid from the box by removing the 4 corner screws. Check that the potentiometers, LEDs, and power switch fit snugly into the holes (Figure M). If not, enlarge the holes accordingly.

3c. Trim the pot shafts.

Use a clamp and hacksaw to cut the potentiometer shafts to about 12mm (Figure N).

3d. Label the box.

Use a label maker to label the green LED hole "Pass," red LED hole "Fail," and the yellow LED hole "Status." Also label the On and Off positions of the power switch (Figure O).

Test-fit the potentiometers, turn them all the way counterclockwise, and put the knobs on, pointing 45° down and to the left. Label the left knob "Diastolic" and the right "Systolic." To "calibrate" them, label the Diastolic knob's minimum position (fully counterclockwise) as 60. Turn it all the way clockwise, and mark its maximum as 110 (all units are mmHg). Add intermediate markings, e.g., halfway between 60 and 110 would be 85.

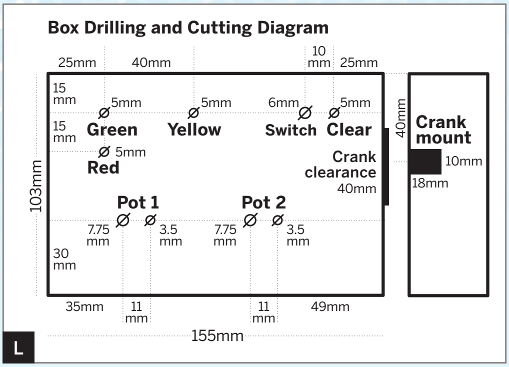
Label the Systolic knob's minimum (fully counterclockwise) as 100. Turn it all the way clockwise and mark its maximum as 180. Add intermediate markings.

3e. Mount the hand crank.

Saw a rectangular section out of the right side of the box, 10mm wide and 18mm deep, centered 40mm from the right edge (Figure P).

Test-fit the crank. The crank housing should be flush against the inside of the box and also flush with the lid edge (Figure Q).

To make the box lid fit, file down or cut out the lip of the lid where it meets the crank. We filed out a 40mm section of lip starting 25mm from the top side of the box (Figures L and P).



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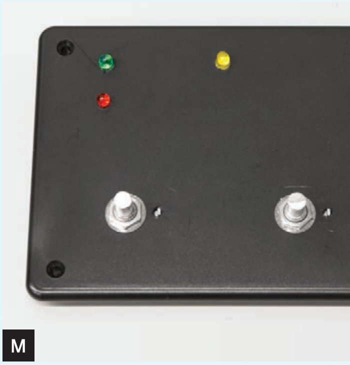
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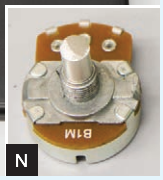
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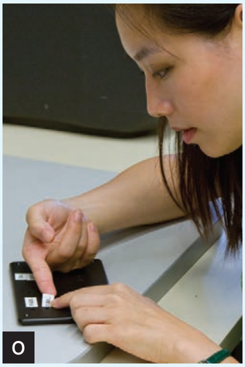
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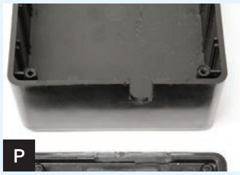
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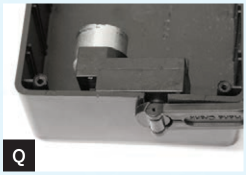

Q

3f. Fit the air hose.

Drill an 8mm hole in the top side of the box, 15mm from the lid edge and 55mm from the left edge (Figures R, T, and U).

Remove the manometer from the tubing that's attached to the cuff (Figure S). Check that the tubing from the cuff fits through the hole you drilled (Figure T).

Damien Scogin (L)

4. PUT IT ALL TOGETHER

Place the batteries in the battery holder and put the battery holder in the bottom of the project box. Slide the hand crank into its hole in the side of the box. Insert the LEDs, potentiometers, and switch into the lid. Attach the loose end of the tubing to the pressure sensor. Place the lid on the box and reattach it with the original screws (Figure U).

Finally, turn the potentiometer shafts counterclockwise as far as they'll go, then reattach the knobs so the markers are pointing 45° down to the left, indicating the minimums you labeled. You're done!

USE IT

To test your blood pressure with the SEA-BPM:

1. Turn the potentiometers to select the desired systolic and diastolic pressure limits.

2. Switch the device on. The power LED should blink intermittently. If it doesn't, try charging the batteries by turning the switch to the Off position and winding the hand crank for 30 seconds before turning it on again.

3. Attach the cuff around the arm just above the elbow.

4. Inflate the cuff using the hand pump. Make sure the valve next to the pump is closed. Stop pumping when the yellow Status LED lights up.

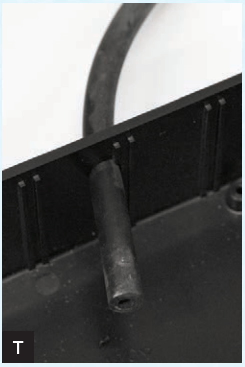
5. Gently open the valve a little, allowing air to slowly escape. It should take about 15 seconds for the cuff to fully deflate.

6. Watch the Pass/Fail LEDs to see which one lights up. Green indicates that blood pressure is within the chosen limits. Red indicates that blood pressure is above the chosen limits.

If both light up, it means there was an error during the measurement, likely due to the cuff deflating too quickly or slowly. Try again.


R

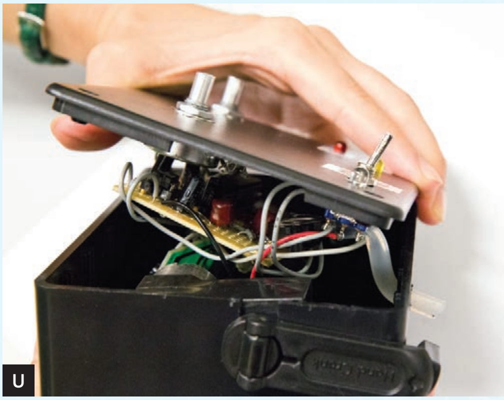

S


T

TOO MUCH PRESSURE

Blood pressure, one of your vital signs, is the pressure exerted by circulating blood on the walls of your blood vessels as your heart pumps. During each heartbeat, it varies between the minimum (diastolic) and maximum (systolic) pressure. In the U.S. classification, you'd ideally have systolic pressure at 90–119 and diastolic at 60–79 millimeters of mercury (mmHg). If either of them is raised, you have high blood pressure, aka hypertension.

Blood pressure rises with age. It's also affected by exercise, stress, diet, and sleep. If it stays high over time, it can damage the body in many ways, including heart failure and stroke. Hypertension disorder occurs in 5%–14% of all pregnancies and is the leading source of maternal mortality.


U

WARNING: This is an experimental prototype. Do not rely on the measurements taken with this instrument. Get your blood pressure checked by a physician.

Download project code: makeprojects.com/v/29

Alex Russell, Garrick Orchard, and Carol Reiley are doctoral researchers at Johns Hopkins University.

TACIT: A HAPTIC WRIST RANGEFINDER

This ultrasonic "bat glove" lets you feel things at a distance.

BY STEVE HOEFER

Gregory Hayes

Tacit is a wearable system that translates the distance to anything you aim your hand toward into pressure on your wrist. The closer the object, the greater the pressure. Sweep your hand around, and the device conveys to you a tactile image of your surroundings. I designed Tacit to help vision-impaired people navigate their environments, but it's also a fun and effective sensory enhancement for fully sighted people — especially in the dark.

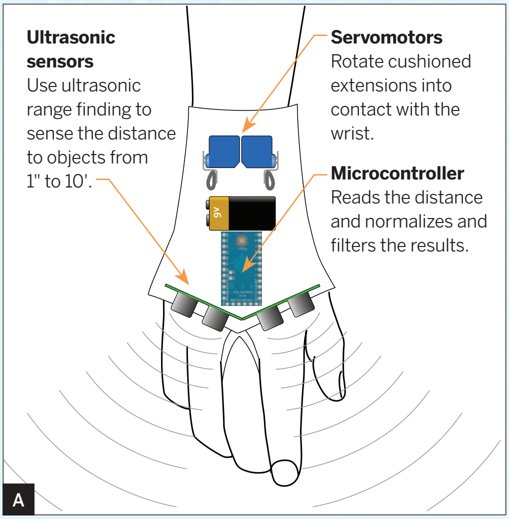
Steve Hoefer (grathio.com) is a technological problem solver in San Francisco. He spends much of his time trying to help technology and people understand each other better.

MY FIRST VERSION OF TACIT WAS A headband with vibration motors that ran faster when objects came closer. But this design had a distracting "mad science" look, and most obstacles, like furniture, are below head level. I also found that motors vibrating against your skull will quickly drive you insane.

I realized that it was my own sighted prejudice to want to attach vision-simulating sensors to the head. The hand is more directable and useful, and putting a device on the back of the wrist leaves the fingers free.

For rangefinders, I used two $30 ultrasonic sensors that detect objects up to 10' away, angled apart to take in a broader swath. I looked at smaller infrared sensors, but they were confused by sunlight, remote controls, security cameras, and absorbent surfaces. Laser rangers would be the most accurate, but they're far more expensive.

The rangefinders input to an Arduino Pro Mini, which controls 2 small servomotors to rotate flexible rubber extensions into the back of the user's hand (Figure A). The servos have a split-second response time, which gives the Tacit an intuitive feel. Everyone who has worn the device figures it out immediately.



A

1. ASSEMBLE THE ELECTRONICS

To carry all the wiring, I made a shield for the Pro Mini using perf board and headers. Start by soldering 12×1 male pin header rows along the sides of the Mini. Cut a piece of board to 9×12 holes and solder two 12×1 female headers so that it will plug on top of the Pro Mini with 2 extra rows along one side for the power switch.

MATERIALS

Ultrasonic distance sensors, Parallax Ping (2) Maker Shed #MKPX5, makershed.com
Microcontroller, Arduino Pro Mini 5V/16MHz Any 5V Arduino or compatible will work, such as Arduino Nano (Maker Shed #MKGR1) or Ardweeny (Maker Shed #MKSB012) — but not the 3V Arduinos.
Servomotors, hobby, 9 gram (2) such as Turnigy #TG9 or Hextronix #HXT900
Perf board, sized or cut to 9×12 holes
Pin header rows, breakaway: straight female (1×24), straight male (1×24), right-angle male (1×12)
Wire, 20–22 gauge, insulated, stranded, various colors
Battery, 9V
Snap connector for 9V battery
Switch, SPDT slide
Machine screws, 2.5mm×8mm (or 4-40×3⁄8"), with nuts and washers (6)
ShapeLock, about 35 grams or other low-melting-point polycaprolactone plastic for modeling
PET plastic sheet, 1⁄16" thick, 3"×3" or larger or other hard flat plastic you can heat and bend. I used PETG from mcmaster.com, part #85815K11.
Rubber or vinyl strip, 6"×1" I used a squeegee blade.
Neoprene, 3mm thick, 12"×12" or 2mm thick, which is cooler to wear
Hook and loop tape, non-adhesive, 12" aka velcro
Bias tape, 4" from a fabric store
Zip ties, small
Epoxy

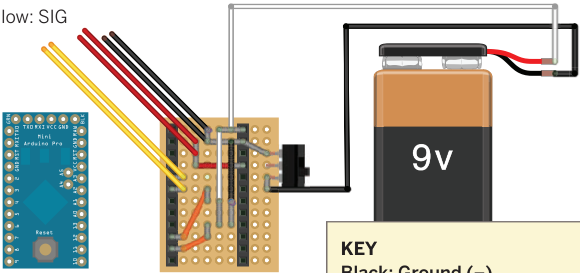
TOOLS

Soldering iron and solder
Container, small, filled with hot water
Scissors
Drill and drill bit: 2.5mm
Sewing machine, relatively heavy-duty or thick needle, strong thread, and patience
Converter cable, FTDI 3V3, USB to TTL or a USB cable with an Adafruit FTDI Friend, Maker Shed #MKAD22
Computer with USB port and internet connection
Software: Tacit project code available on Github, gist.github.com/1175994
Template for cutting neoprene download at makeprojects.com/v/29

Steve Hoefer

Layout and Assembly

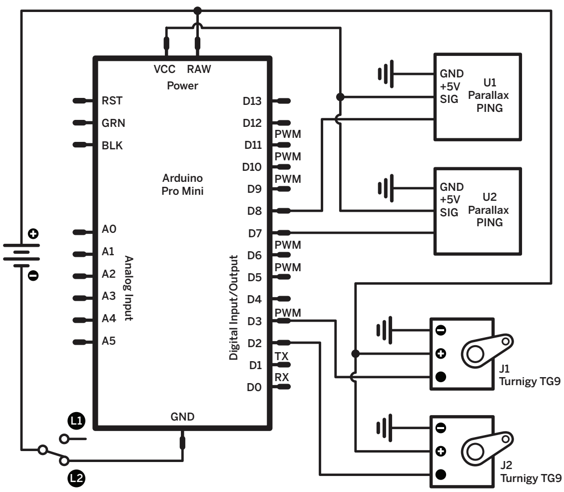
Connection to Parallax Ping ultrasonic sensors:
Black: GN
Red: +5V
Yellow: SIG



Header pins at the right match the Arduino Mini Pro pin layout at the left. Two 3-pin horizontal male headers (not shown) connect the servos.

KEY
Black: Ground (–)
White: +9V unregulated
Red: +5V regulated
Yellow: Ultrasonic sensor signal
Orange: Servo signal
Gray: Bridged connection

B



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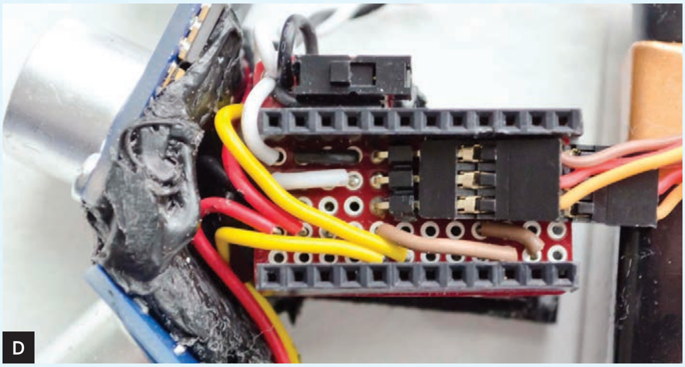


D

Solder a 6×1 right-angle header to the top of the Pro Mini, for programming, and two 3×1 right-angle headers to the shield for plugging in the 2 servo cables.

Follow the diagram and schematic (Figures B and C) to wire up the shield. Connect the 9V battery (+) to RAW power on the Arduino and the middle (+) servo header pins. Connect battery (–) to Arduino GND through the switch, and directly to sensor and servo grounds. Connect Arduino VCC to sensor power. Finally, connect Arduino digital I/O pins D7 and D8 to the sensor signal (SIG) contacts, and pins D2 and D3 to the servo signal pins.

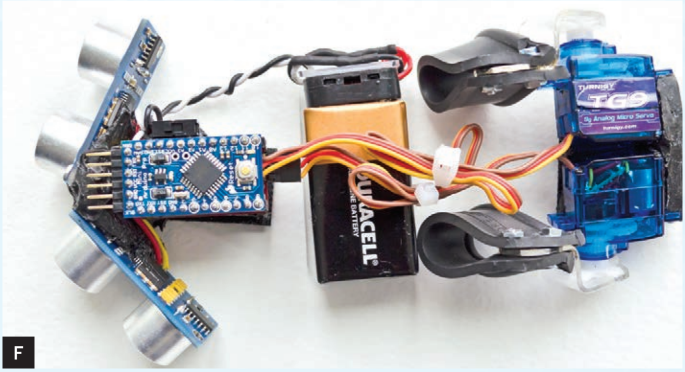
2. MOUNT THE SENSORS AND EFFECTORS

Melt the ShapeLock in hot water and mold it into a bracket that joins the 2 sensors onto the top end of the shield and angles them apart at about 120° (Figure D). Make sure not to block the programming header. For extra hold, run small screws through the sensor board mounting holes and into the ShapeLock while it's still soft.

Join the servomotors back-to-back with more ShapeLock. Cut 2 tabs out of the PET plastic, about ⅜"×1¼" each. Heat them crossways over the soldering iron without touching it, and bend each into a symmetrical right-angle S-bracket. Drill

Damien Scogin (C)

E



F

and mount each bracket to a loop of cut rubber and epoxy the other end to a servo horn (Figure E). Lay out the 2 assemblies with the battery in between (Figure F). The mechanism is done.

3. PROGRAM THE ARDUINO

Download and install the Arduino IDE from arduino.cc. Download the Tacit project code from gist.github.com/1175994.

Open the project code in the Arduino IDE. In the Tools → Board menu, choose your model of Arduino, and under Tools → Serial Port select the COM port, the highest number if you see more than one.

Plug the USB-TTL cable (or USB cable and FTDI Friend) between your computer and the Pro Mini. Click Verify and Upload to compile the code and burn it to the controller chip.

4. MAKE THE GAUNTLET

Download the template for the gauntlet at makeprojects.com/v/29 and use scissors to cut the shape out of neoprene.

Cut and sew velcro strips onto the neoprene where indicated, and sew on a loop of bias tape to fit the middle finger in front of where the Arduino sits.

TIP: Neoprene is a challenge to sew. It drops stitches like crazy on a sewing machine, so you should use the biggest needle you can, with thick thread, and cover the neoprene wherever you sew with a piece of thin scrap cloth. (Thanks to Bethany Shorb of Cyberoptix Tie Lab for the tip!)

Use super glue to attach the corresponding velcro pieces to the electronics and the plastic brackets. The velcro lets you remove the electronics and launder the neoprene. Stuff that's near the hand can get dirty surprisingly fast.

Electronics sewn into wearable material will inevitably flex, but solder joints can't take much bending before they break. So wherever possible, you should loop the wire through holes and use zip ties to give each connection plenty of play. I learned this lesson the hard way when I made my Rock Paper Scissors Playing Glove (that's another story, at makezine.com/go/rpsglove).

IMPROVEMENTS

Now I'm working on Tacit 2.0, refining the software, shrinking the hardware, and using a rechargeable battery with some kind of blind-friendly charging method, either wireless or a magnetically-aligning power plug.

Download the Tacit project code at gist.github.com/1175994 and the neoprene cutting template at makeprojects.com/v/29.

Many thanks to the designers at Device Design Day, who gave me tons of positive feedback on earlier versions of Tacit.

HACK YOUR HEAD

WE HAVE THE TECHNOLOGY

Brain Rave

Need to chill out in a hurry? In a mere 14-minute cycle of flashing light patterns and techno bleeps, Mitch Altman's Brain Machine Trip Glasses take you on a round-trip voyage to a universe deep inside your mind. Sound and light machines (SLMs) generate pulses at brain wave frequencies to mesmerizing, meditative effect.

Pick up a fully assembled pair at the Maker Shed (makershed.com) or build your own (*see MAKE Volume 10, makezine.com/10*).

Sam Murphy

EEG Your Ride

Why settle for robotic chauffeurs when your brain can become part of the driving system? German researchers found that combining driver EEG readings with computer-controlled braking systems increased braking reaction time by 130ms, which makes a difference of almost 13 feet at 60mph. Car manufacturers are already experimenting with NeuroSky EEG readers in headrests to combat snoozing at the wheel, so braking with a thought might not be far away. makezine.com/go/eegcar

—Craig Couden

CHOSCILLATOR

Sean McIntyre invited attendees of Maker Faire New York 2011 to play mental tug of war with a computer through his interactive installation, the Choscillator, made from a hacked Mattel Mindflex, a computer, and a steel-frame chair. The computer alternates between requesting the human to focus, then to relax, switching when the requested state is achieved, thereby "mimicking our relationship with new immersive technologies," says McIntyre. www.boxysean.com/projects/choscillator.html

—Goli Mohammadi

SLEEPERS

If you hung around Maker Faire New York's Health 2.0 pavilion last year, you probably saw Brian Schiffer's brain in action — literally.

Schiffer, an electrical engineering student at Cornell, hacked a Zeo sleep monitor (hidden in his fedora) to output real-time brain activity via Bluetooth to an Android tablet worn around his neck.

Schiffer's hacking skills landed him a consulting gig with Zeo to explore open source development and make the Zeo monitors more hacker friendly. blog.myzeo.com/turning-a-hacker-into-an-asset

—CC

Berlin Institute of Technology (EEG); Chris Jordan (Choscillator); Jeremy Blum (ZeoHack)

LAST STRAW

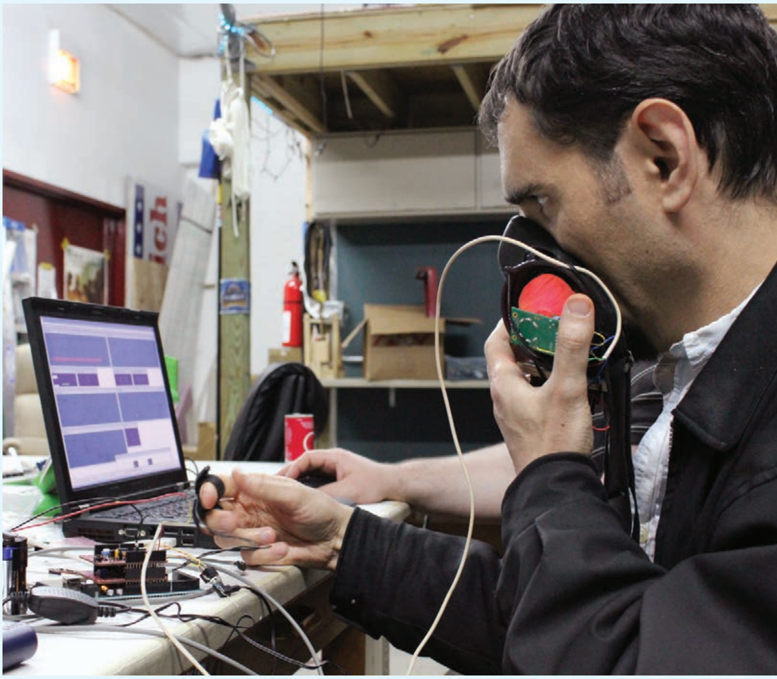
Safe drinking water is a huge issue in much of the developing world. With this in mind, Swiss company Vestergaard Frandsen developed LifeStraw, a light, portable, straw-style water filter. The 10"-long, 1"-diameter device is simple to use: suck on the straw to filter and consume water; blow through the straw to clean the filter. It filters enough water for one person for a year and removes most of the bacteria, viruses, and parasites. vestergaard-frandsen.com/lifestraw

—Laura Cochrane

Future Geniuses

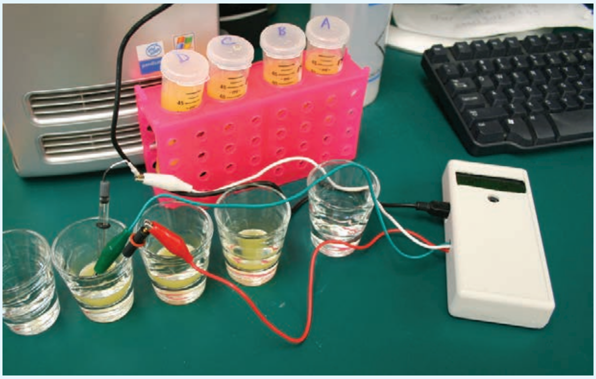
Pumping Station One's Biosensor Array, a finalist in the Great Global Hackerspace Challenge, consists of a series of electronic tools designed to help middle school and high school students measure — and therefore learn about — their own biological processes. The heart of the system is an ordinary Arduino, and the array consists of sensors measuring body temperature, oxygen saturation, EKG, galvanic skin response, respiratory volume and frequency, as well as CO^2 output. makezine.com/go/biosensor

—John Baichtal



CHEM LAB ON THE CHEAP

CheapStat is an open source, inexpensive, DIY potentiostat (electrochemistry instrument) designed by a team of electrical engineering students from UC Santa Barbara working with chemists. Conceived with resource-poor developing countries and undergraduate laboratories in mind, CheapStat can check water for arsenic, measure the level of vitamin C in orange juice, perform simple DNA biosensor tests, and more. The design team plans to come up with more cheap, nonproprietary chemistry gadgets in the future.
makezine.com/go/cheapstat —*LC*



"Innovations in biology should be accessible, affordable, and open to everyone."

DIY DNA

Ever wish you could peer inside your own DNA? Stop wishing, and start building the (relatively) inexpensive OpenPCR kit. Coupled with open source software for Mac or PC, this handsome DIY thermocycler lets users select and replicate segments of DNA to test for any number of genetic conditions. Since its release in July 2011, the kit has been demonstrated with tests for particular muscle performance traits and aversion to Brussels sprouts, and has been used in the wild to check foods for telltale GMO markers. openpcr.org
—*Gregory Hayes*

BioCurious?

San Francisco Bay Area's BioCurious biotech hackerspace believes "innovations in biology should be accessible, affordable, and open to everyone." Their fully stocked 2,400 sq. ft. biology lab and technical library is open to members for a monthly fee. They also host classes and weekly meetups, and boast a growing community of novices and experts alike.
biocurious.org —*GM*

Aaron Rowe / Plaxco Lab (CheapStat); Tito Jankowski (BioCurious); Josh Perfetto (DNA); Vestergaard Frandsen (LifeStraw, opposite)

SMART SHOES

Anirudh Sharma of India has designed an open source vibrating shoe to assist blind people. Named Le Chal, Hindi for "take me there," the system employs a LilyPad Arduino, eight vibrational motors, and Bluetooth. The user speaks a destination using a smartphone, Google Maps loads directions into the shoe via Bluetooth, and when appropriate, it vibrates in an area of the shoe, indicating the direction in which to turn. makezine.com/go/lechal

—*LC*

Highly Textured

Experience the world of touch in a new and unique way with the Touch Glove. Information from the resistive-fabric sensor in the index finger appears as light patterns displayed on an LED grid sewn into the cuff. Designer Ally Seeley wanted a way for people with impaired senses of touch to interact with textures, in this case, visually with lights. makezine.com/go/touchglove —*CC*

MAGNETIC TOUCH

Leigh Honeywell had a manicurist apply tiny parylene-encapsulated rare earth magnet discs onto her fingernails amid multiple layers of nail gel, giving her a sense most of us lack. "I can feel ferrous materials strongly and easily with the backs of my fingers," she reported. "It's a very gentle pull and is totally fascinating." makezine.com/go/fingernails

—*JB*

3D-PRINTABLE TRAUTMAN HOOK

The Open Prosthetics Project aims to bring the tenets of the Open Hardware movement to the field of prosthetics, which is hindered by patents and companies' focus on profits over patients. The Trautman Hook is an obsolete artificial hand that serves more as a promise of what is possible, rather than a solution in itself. Print one out and see for yourself. thingiverse.com/thing:2194 —*JB*

"Prosthetics shouldn't cost an arm and a leg."

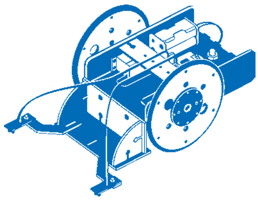
LEGO MY HAND

Why fork out $30,000 for a prosthetic hand when $500 worth of Legos can do the same job? The Open Prosthetics Project encourages public collaboration in prototyping low-cost prosthetics. They've achieved a hand with an articulated wrist, independently moving fingers, and an opposable thumb. Next step is to add motor and sensor systems. If the idea clicks with you, collaborate at openprosthetics.org. —*GH*

Carly Nartowicz (Skywalker)

On Wings of DEMONS

At Massachusetts' Concord Academy, the real angels are DEMONS (Dreamers, Engineers, Mechanics, and Overt Nerds), the school's invention club, who helped Luke, a faculty member's son diagnosed with cerebral palsy. Improving on expensive suspension walkers, the team's device, Luke's Skywalker, encouraged Luke's mobility by allowing him to walk directly up to activities and friends. makezine.com/go/skywalker —*GH*



TINY WANDERER

Starter robot autonomously navigates with a $2 microcontroller.

By Doug Paradis

In early 2011 my robot club, the Dallas Personal Robotics Group (dprg.org), was looking for a way to help our beginning members build up their skills. To this end, we produced a series of lessons covering 5 topics needed to make a simple, programmable robot: making PCBs with the toner transfer method, programming ATtiny microprocessors, laying out circuit boards using KiCAD, using Inkscape to design robot parts, and programming state machines. Videos of these lectures are available on DPRG's website.

The Tiny Wanderer is the starter DIY robot model we designed to support the series. It uses the unintimidating ATtiny85 chip, which is less complex than larger chips, and the new kit version shown here lets you easily swap in an Arduino.

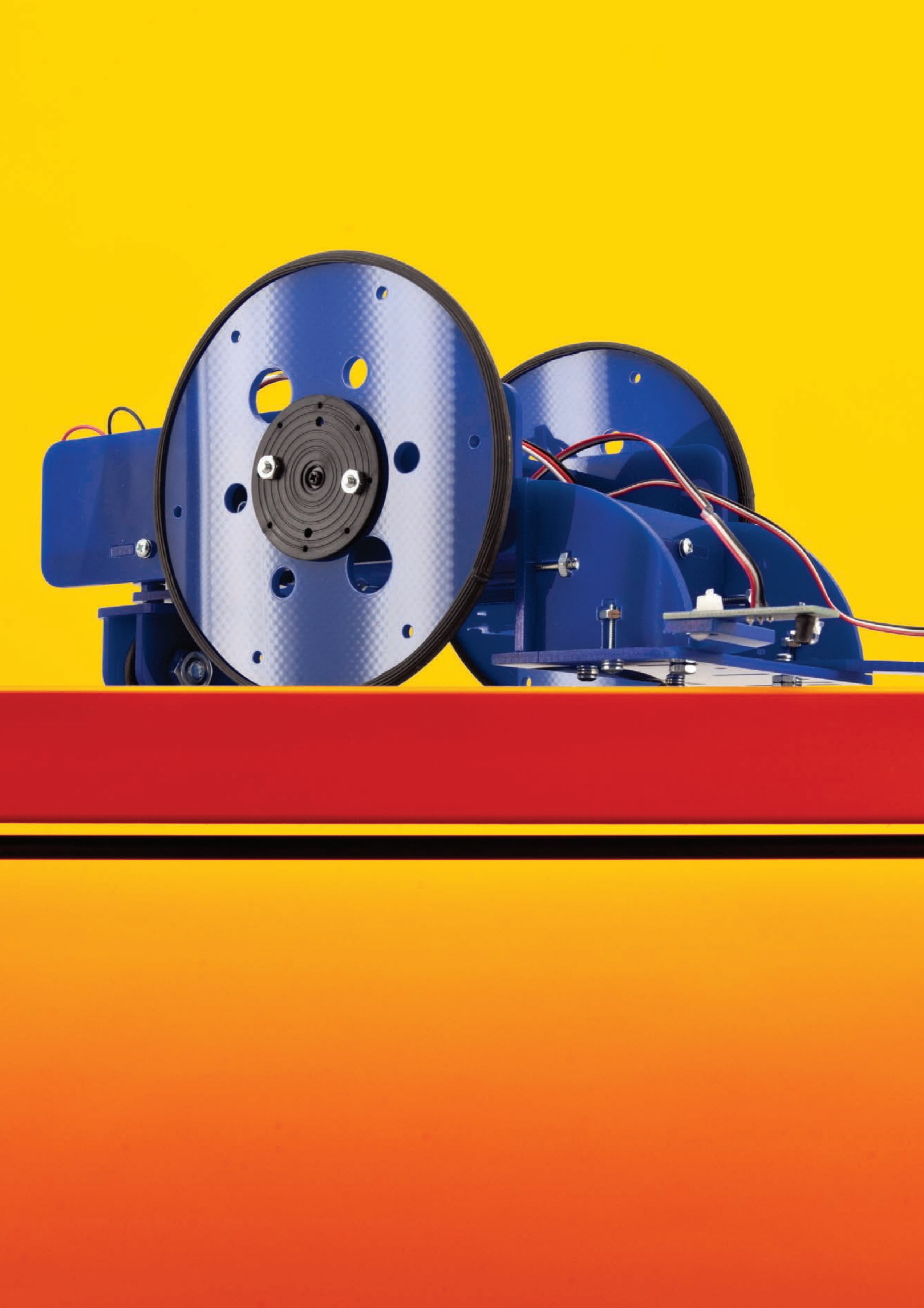
The chassis, inspired by the now-discontinued Oomlout SERB, has benefited from constant modification and tweaks by DPRG members. Its two IR LED/sensor proximity "feelers" were originally designed to let the bot wander around a tabletop without falling off, but they can be repurposed for obstacle avoidance and line-following. (Another successful mod added 64-slot encoders on the wheels, for dead reckoning.)

I hope the fun we've had with Tiny Wanderer will be shared with other hobby roboticists and makers around the world.

Doug Paradis is a member of the DPRG and Dallas Makerspace. His interests include microcontrollers, robots, crafts, and fishing. He suffers from laser cutter and CNC router envy.

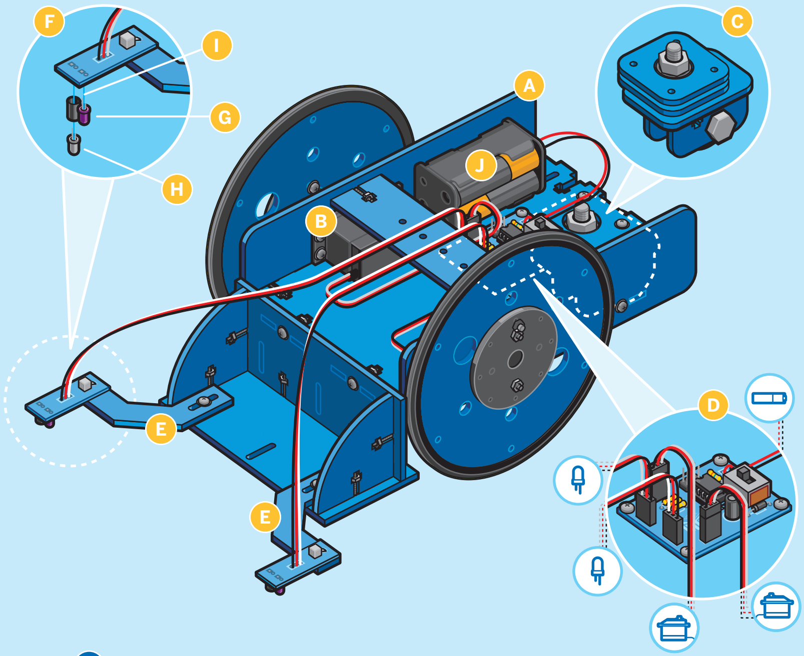
Gregory Hayes

SET UP: p.91 | MAKE IT: p.92 | USE IT: p.99



AVOIDING A FALL

The Tiny Wanderer uses 2 DIY infrared proximity sensors and a cheap 8-pin microcontroller chip to autonomously navigate tabletops, obstacle courses, or black-line paths, depending on the sensor placement and chip programming.



A The robot's **chassis** is bolted together from flat-cut pieces.

B The 2 **servomotors** each drive a large wheel with a rubber tire.

C A swiveling **caster** centered under the chassis rear provides a third wheel, for balance.

D The **PCB** holds an **ATtiny85 microcontroller** chip, its programming header, connection headers, a power switch, and other supporting components. In this project, the ATtiny85 is programmed in C, with its hexfile firmware generated by the GCC compiler.

E A sensor tray in front of the chassis holds the 2 **sensor arms**.

F On the end of each arm is a **sensor board**.

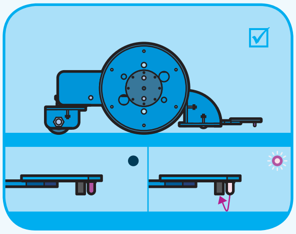
G Each sensor board has an **infrared (IR) LED** that's switched on and off by the microcontroller.

H Next to each IR LED is an **IR phototransistor** that becomes more conductive when it sees more infrared. When a reflective object is close to the sensor board, the phototransistor detects IR bounce-back from the LED.

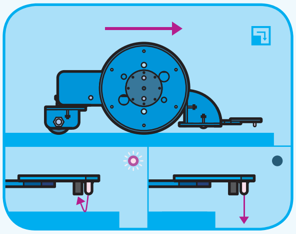
On the PCB, the collectors of the phototransistors are connected to VCC through pull-up resistors and to analog input pins of the microcontroller. This allows the microcontroller to monitor the IR levels detected. With this input, it controls the servomotors according to programmed behavior — for example, by backing the robot up when the sensors detect that it's about to roll off the table.

I A small piece of unshrunk **heat-shrink tubing** blinders the phototransistor, shielding it from IR that comes from the LED directly.

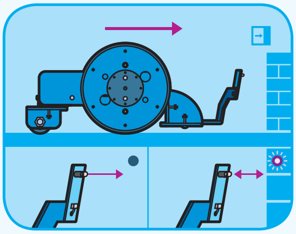
J A **4×AA battery pack** supplies power to the servos and microcontroller.



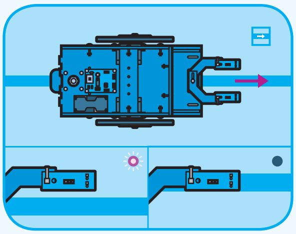
1. Before the robot starts wandering, the code calibrates each sensor against the table surface by measuring the phototransistor's output with the IR LEDs both off and on.



2. As the robot travels, the IR LEDs blink on and off, and the code compares the sensed difference in IR bounce-back with the difference seen during calibration. If there's no bounce-back — danger, Tiny Wanderer, danger!



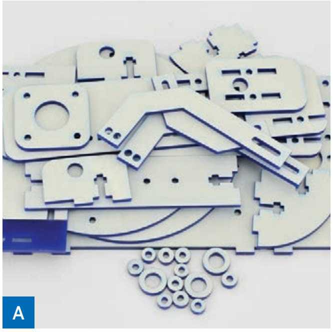
3. Face the same 2 sensors forward, and you can program the Tiny Wanderer to avoid obstacles in its path.

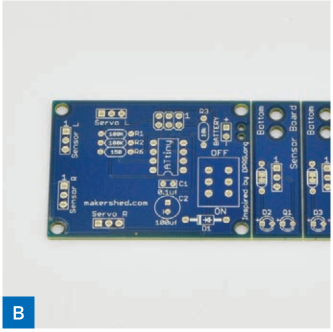


4. Move the sensors closer together, facing down, and you can program the Tiny Wanderer to follow a black line.

Rob Nance

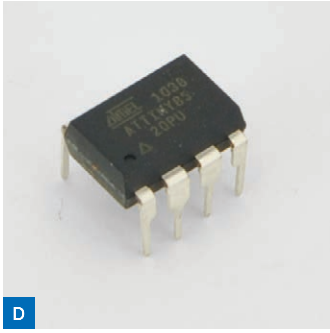
SET UP.


A



B


C


D


E


F

MATERIALS

All parts (except batteries) are included in the Tiny Wanderer Kit (MSTW01) from the Maker Shed (makershed.com), $179.

A. Plastic body and wheel parts, 1/8"-thick acrylic, laser cut You can download SVG and PDF cutout templates at makeprojects.com/v/29. You can also hand-cut the body out of 1/8" masonite (aka hardboard).

B. Tiny Wanderer circuit board Layout files are at makeprojects.com/v/29. You can also use plain perf board and hookup wire.

C. Servomotors, hobby, continuous rotation, 6V, with round attachment horns (2)

D. Microcontroller chip, Atmel ATtiny85 about $2

E. LEDs, 940nm infrared (IR), 3mm or 5mm (2)

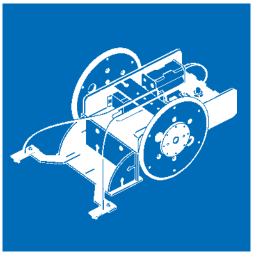
F. Phototransistors, 940nm IR, 3mm or 5mm (2) aka photodetectors or phototosensors. RadioShack sells a 5mm LED/sensor pair, #276-0142, radioshack.com.

» **Diode, 1N4001** or similar
» **Resistors: 150Ω (1), 10kΩ (1), 100kΩ (2)**
» **Capacitors: 0.1μF (1), 100μF (1)**
» **Slide switch**
» **DIP socket, 8-pin**
» **Pin headers: female 8×1, male 20×1**
» **Ribbon cable, 3-conductor, 3'** aka servo cable
» **Heat-shrink tubing, 1/4"×1" length**
» **Bearings, in-line/skateboard, type 608ZZ (2)**
» **O-ring, rubber, 22mm** or other outside diameter to match bearings
» **Bolts, 5/16"×1" (2)**
» **Nuts, 5/16" (2)**
» **Machine screws, #4-40: 3/8" long (18), 5/8" long (22)**
» **Nuts, #4-40 (40)**
» **Washers, #4-40 (22)**
» **Window screen spline, vinyl, 0.175"×26"**
» **Velcro dot pair, adhesive backed**
» **Zip ties, small (2)** plus 2 more each time you reconfigure the sensors
» **Battery holder, 4×AA**
» **Batteries, AA (4)**

TOOLS

» **Soldering equipment and solder**
» **Screwdriver**
» **Tweezers**
» **Seam ripper**
» **Paper and pencil**
» **Sandpaper, fine**
» **Utility knife**
» **Protractor**
» **Scrap wood**
» **Heat gun (optional)**
» **Cyanoacrylate glue** aka super glue
» **Multimeter with voltmeter and ohmmeter functions**
» **ISP (in-system programmable) programmer for AVR microprocessors** I use the AVRISP mkII, $34 direct from Atmel Corp. (atmel.com). There are less expensive options, but non-Atmel programmers may lag in supporting new chips and drivers. Only update your programmer using firmware from its manufacturer. If your programmer has a 10-pin header, you also need a 10-pin to 6-pin AVR ISP adapter, which you can make or buy for less than $5.
» **Computer, Windows-based, with internet connection** You can use Linux or Mac OS, but you'll need a different software tool chain than described here.
» **Software: WinAVR and AVR Studio 4** Download from winavr.sourceforge.net, and search "AVR Studio 4" at atmel.com.

MAKE IT.

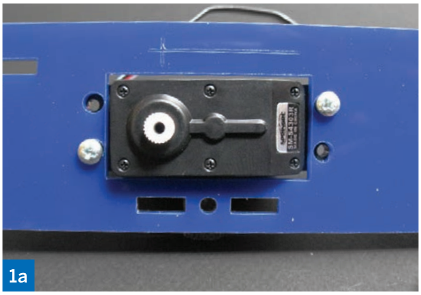


BUILD YOUR TINY WANDERER ROBOT

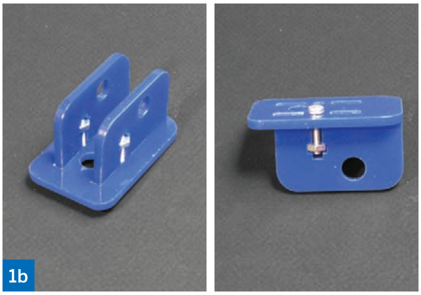
Time: A Weekend
Complexity: Moderate

1. BUILD THE CHASSIS

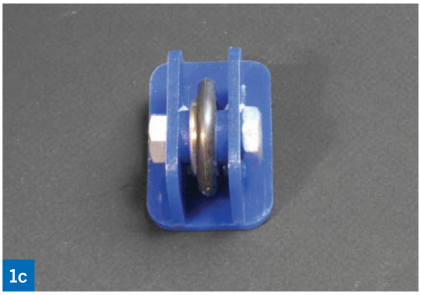
1a. Peel the protective plastic off all acrylic parts. Insert the rubber grommets packaged with the servos into the 4 servo mounting holes. Use four #4×3⁄8" screws to attach each servo to one of the 2 acrylic side pieces, with the shaft aligned with and on the same side as the etched guideline. With the motors installed, align the side pieces next to each other and make sure they match up.


1a

1b. Fit the 2 acrylic axle holders into the bottom of the truck piece. Anchor each one with a nut in its cross-shaped cutout, screwed onto a #4 screw threaded through a washer from the top of the truck.


1b

1c. Fit the O-ring around one of the skateboard bearings. This will be the rear caster's wheel. Mount it between the axle holders, with a large acrylic washer on either side, on a 5⁄16"×1" bolt secured with a matching nut.


1c

NOTE: See makeprojects.com/v/29 for photos identifying all the acrylic kit pieces.

TIP: Place the first 2 screws in diagonal corners, and don't tighten any screws until they're all in place.

Doug Paradis

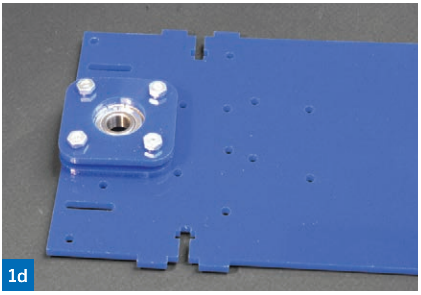
1d. For the caster's swivel mount, run four #4 screws through 4 small metal washers, then through the 4 mounting holes around the rear caster hole in the large acrylic base piece. Drop the bearing holder (the acrylic square with the larger center hole) over the 4 screws. Drop the bearing into the holder, then drop 4 small acrylic washers onto the screws. Finally, drop the bearing retainer (the square with the smaller hole) onto the screws and over the bearing. Secure with nuts.

The metal washers provide clearance; without them, the caster will hit the screws.

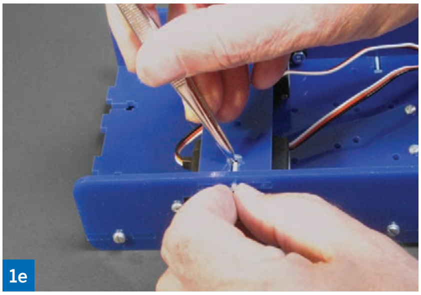
1e. Attach the side pieces to the top of the base by fitting 4 nut/bolt pairs into its cross-slots, as in Step 1b. Use 2 more nuts and bolts to join the tops of the side pieces to the crossbar piece.

1f. Assemble the sensor tray from the sensor shelf, sensor shelf riser, 2 sensor shelf brackets, and 6 nut, screw, and washer sets. As with the other acrylic pieces, fit the tabs into the slots and secure by twisting the nuts down on the bolts in their cross-slots. The sensor shelf will act as a base for attaching the robot's sensors.

1g. Attach the sensor tray to the front of the chassis with 2 screws.



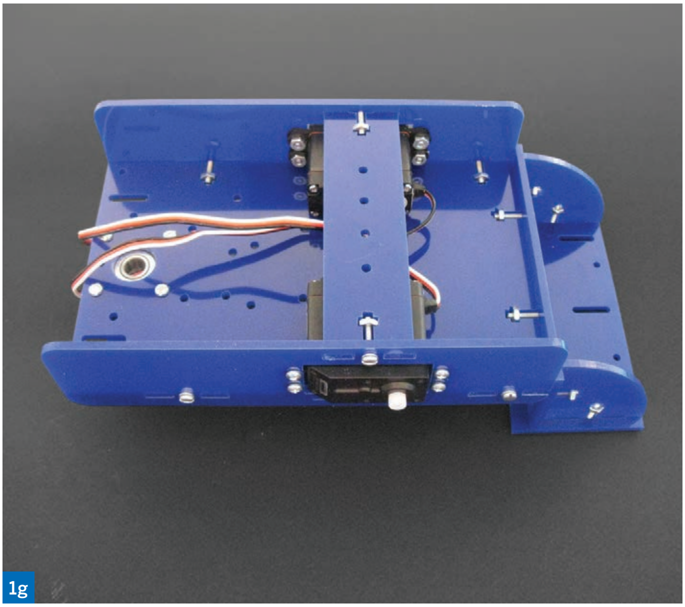
1d



1e

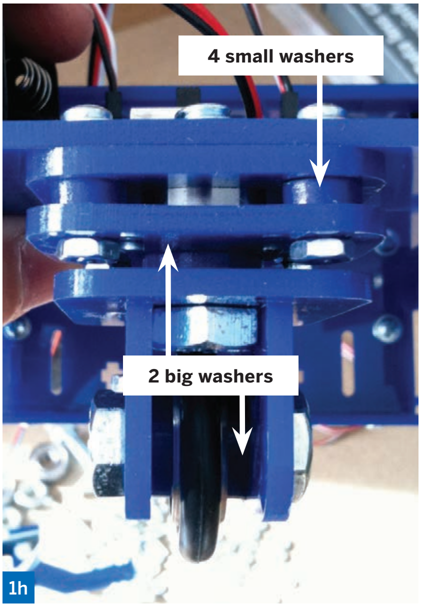
TIP: Tweezers help to hold the nut in place while you start the screw.

1f



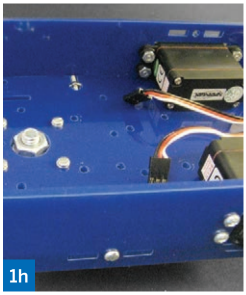
1g

1h. Attach the caster holder to the caster swivel mount with the remaining 5/16" bolt and matching nut. Fit 2 large acrylic washers over the bolt between the underside of the swivel mount and the top of the caster holder, so the caster can turn without mounting hardware getting in the way. The inner race of the horizontal bearing should be clamped between the large bolt head and the 2 acrylic washers.



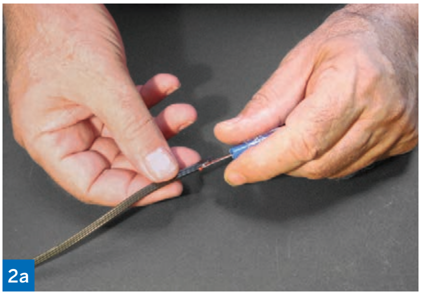
1h

NOTE: You may have to temporarily loosen the screws to get the bolt to fit through the caster assembly so that the bolt's head is captured by the wheel supports.

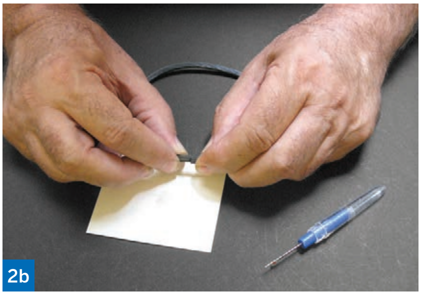

1h

2. FIT THE TIRES AND HUBS

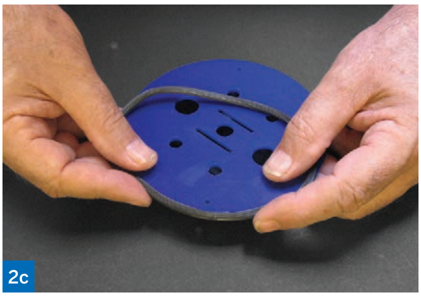
2a. For each of the 2 tires, cut a 12¾" length of window screen spline. Use a seam ripper to puncture each piece about ¼" from one end. Slit the spline along one edge, going almost its entire length, but stopping when the seam ripper point shows at the other end.


2a

2b. Drop a dot of super glue onto a piece of thick paper. Run your finger down the slit to make sure it's not twisted, then align the 2 ends and dip them into the super glue. Hold the ends together for 20 seconds; they should stick together. Put the tire aside for at least 15 minutes.

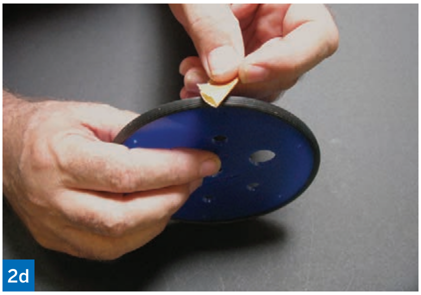

2b

2c. Use the seam ripper to slit the joint area, making the slit continuous. Starting with the joint, place the tire onto the wheel, working it around the rim a little bit at a time.

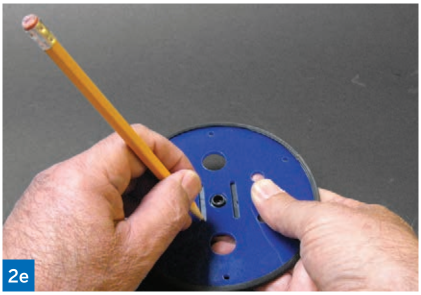

2c

Mark Demers (1h, labeled)

2d. Place a pencil through the center of the wheel and roll it on a table to seat the tire. Use fine sandpaper to lightly sand the glue joint. Be careful — you only want to remove excess glue.

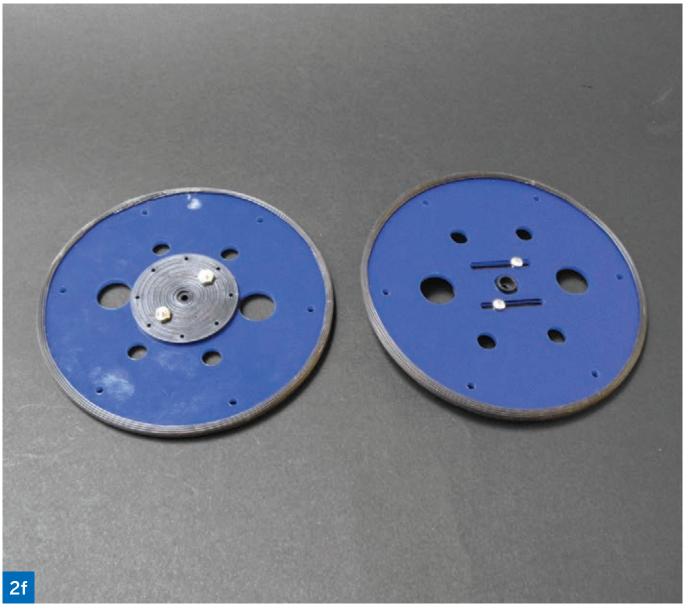

2d

2e. With each circular servo horn, center it under a wheel with the horn hub protruding through. Rotate the horn until you see 2 of its 4 injection-mold marks through each of the wheel's slots. Mark the horn through the 2 slots with a sharp pencil. Drill two 7/64" holes into the horn where the mold marks intercept your lines.


2e

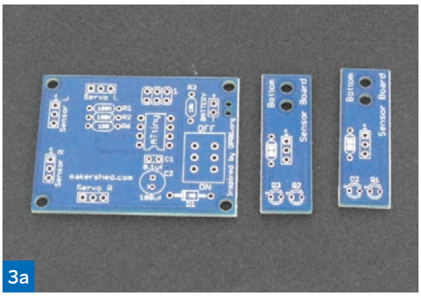

2e

2f. Use two #4 screws and nuts to attach a horn to each wheel, and mount the wheels on the servo axles using the small screw that comes with the servos.

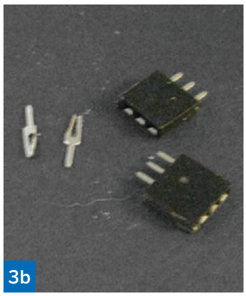

2f

3. ASSEMBLE THE CONTROLLER

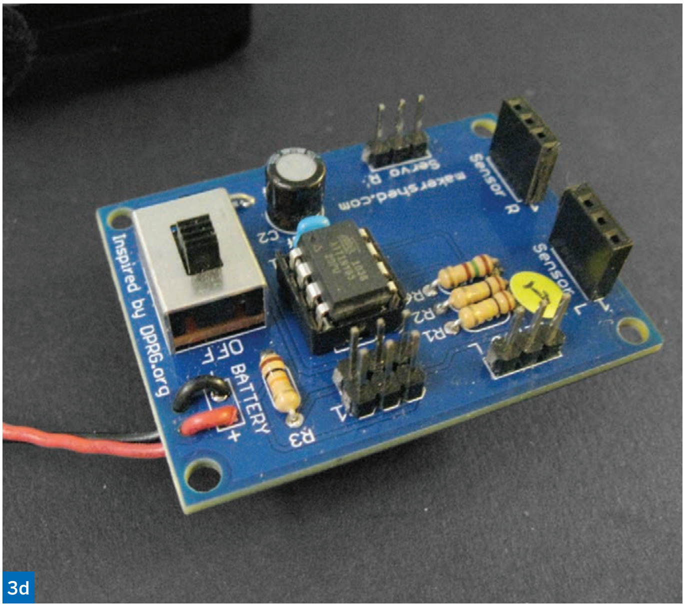
3a. Separate the PCB into 3 boards — the controller board and 2 sensor boards — by splitting it along its 2 scribe lines. You may need to deep-en the scribe line between boards with a utility knife before separating them.


3a

3b. Cut the 8-pin female header into two 3-pin headers by cutting through the fourth and fifth pins. Sand the cut edges smooth.

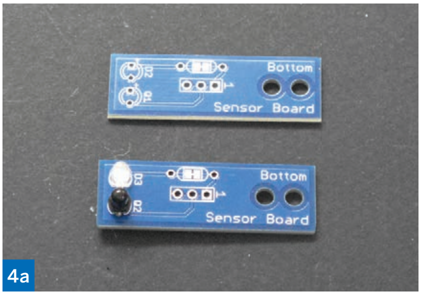

3b

3c. Populate the board with the components as marked, starting with the shortest ones (resistors and diode) and working up to the tallest. Route the battery holder's leads through the strain relief holes before attaching. Make sure the large capacitor's polarity is correct, with the lead near the band marked with negative signs (–) opposite the hole marked (+). The female headers go into the locations marked "Sensor R" and "Sensor L." Do not place the chip into the socket yet.



3d

3d. Use a multimeter to check all connections, following the wiring-check tables at makeprojects.com/v/29. If everything checks out, plug in the chip with its pin 1 near the switch, and its notch next to capacitor C1.



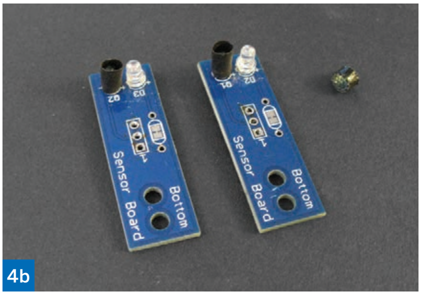
4a

TIP: After any work on the circuit board, perform the checks outlined in Step 3d again before you plug in the chip. Before checking, disconnect the servos and sensors from the controller board and turn the power switch off.

NOTE: The wiring tables list all the pairs of points on the board that should have continuity or a specified resistance.

4. ASSEMBLE THE SENSOR BOARDS

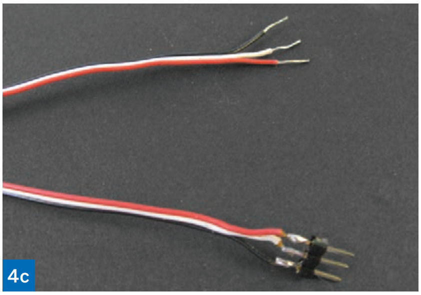
4a. Plug a phototransistor and an LED into each sensor board, orienting the small flat on the side of the plastic lens (the LED's cathode or transistor's collector) as indicated on the board. "D" marks the LED's position and "Q" marks the phototransistor.

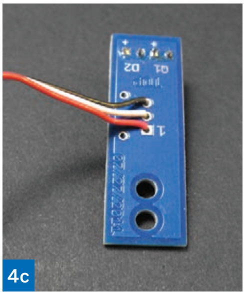


4b

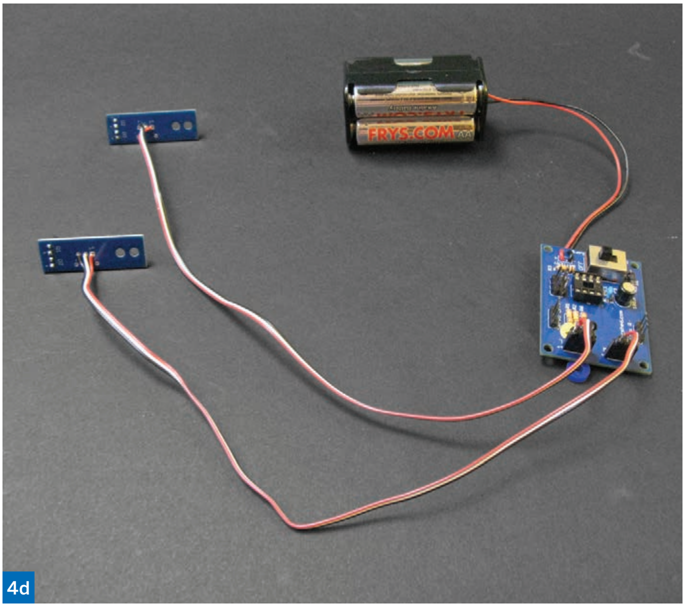
4b. Fit the 1" length of heat-shrink tubing over a phototransistor so that its edge touches the board, then cut it off just above the plastic lens. Similarly fit and trim a piece over the other phototransistor. Do not heat the tubing.

4c. Cut the 3-wire ribbon cable in half. Strip and tin all ends of both pieces. For each, solder one end to a 3-pin male header and the other to a sensor board, with the red wire in the location marked "1."


4c


4c

4d. Plug the cables into the female sockets on the controller board, connecting the red wire to the sides marked "1."

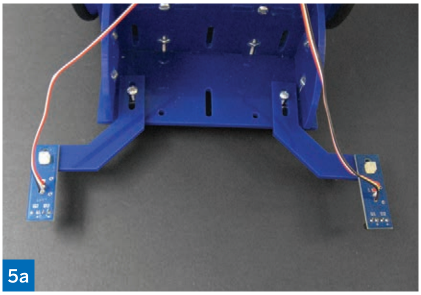


4d

5. MAKE THE SENSOR ARMS

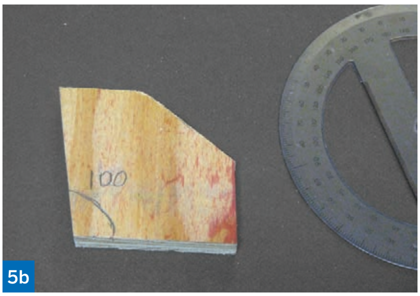
The 2 sets of Tiny Wanderer sensor arms work with 2 different behavior programs: cliff-sensing (for wandering an empty tabletop) and object avoidance. See makeprojects.com/v/29 for a third sensor arm design, for line-following behavior.

5a. *For the cliff-sensing configuration*, use zip ties to attach the sensor boards to the shorter of the 2 pairs of acrylic sensor supports, and bolt the arms to the sensor tray with the phototransistors and LEDs pointing downward.


5a

TIP: When you bend the second arm, make sure it's a mirror image of the first.

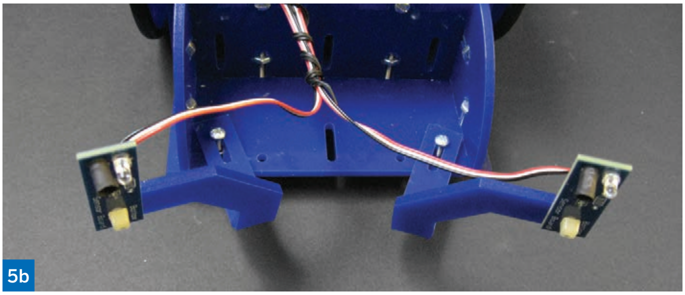
5b. *For the object-avoidance arms*, first make a bending guide by cutting a 100° corner on a scrap of wood. Mark each of the longer acrylic sensor supports 1¾" from its long end, warm it with a heat gun or by holding the heating element of a soldering iron near (but not touching), and then bend it over the guide.



5b


5b

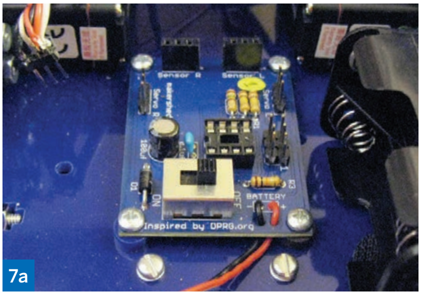
Zip-tie the sensor boards to the object avoidance arms, then bolt the arms to the tray, angled slightly inward to avoid a blind spot in the center.



5b

6. PROGRAM THE ATTINY85

To give the robot its behavior, program the ATtiny85 chip, following the instructions at makeprojects.com/v/29.

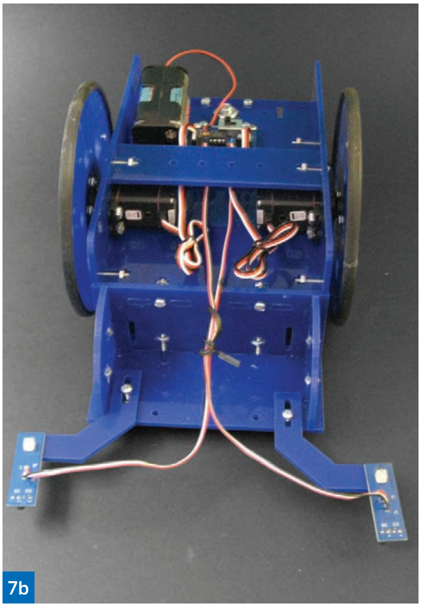


7a

7. FINISHING TOUCHES

7a. Bolt the controller to the chassis with the battery wires pointing rearward. Use small acrylic washers as standoffs under the board. Add velcro for holding the battery case onto the rear of the base.

NOTE: Left and Right as marked on the board are defined with respect to looking at the robot from the front, not as the robot's own left and right.



7b

7b. Plug the servos into the board. If you sourced your own servos, you may need to adjust the speed settings in the *.h* file, due to differences in servos.

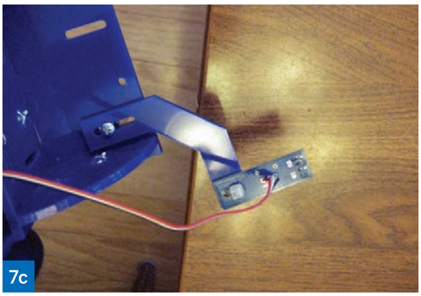
TIPS: You can use zip ties to neaten up the servo wires.

If the servos turn slowly off the table, zero them by adjusting the pots until they stop.

After zeroing the servos, turn the power off for a few seconds to let the large capacitor discharge, and restart the robot back on the table.

7c. To test, hold both sensors over a table and alternately move each off the edge. With both sensors over, the wheels should run forward, and with one off the edge, they should run backward at different speeds.

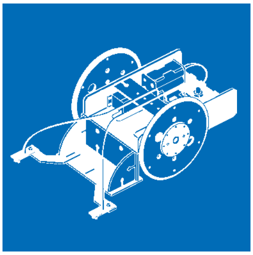
To calibrate the servos, hold the robot in midair and adjust the potentiometers until both wheels sit still. Then turn the power off for a few minutes to let the large capacitor discharge. Your Tiny Wanderer is ready to roll!



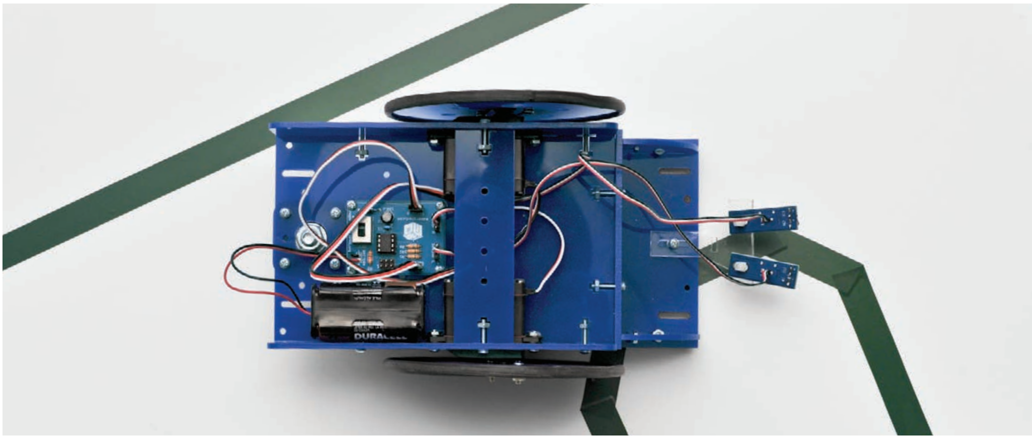
7c

TEST BUILDER: Eric Chu, MAKE Labs

Gregory Hayes (7c)



BLUE TRAVELER



Backup Plan

Because Tiny Wanderer has no rear-facing sensor, it might back off a cliff. Strategies for preventing this are a current "area of research" at the DPRG. In the code you downloaded, the robot backs up while turning away from the detected edge, for about 1 second (about 90°). Then it resumes rolling forward. If both sensors find a cliff at the same time (very rare), it backs up straight. Wheel speeds and backup time parameters are easily tweakable in the code's *.h* file.

You can also change the robot's behavior by moving one sensor slightly ahead of the other. Tell Tiny to turn slightly toward the leading sensor when it detects a cliff, then turn sharply when the trailing sensor finds it. That way, Tiny will do a multi-point turn and then pivot to run along the cliff!

Yet another approach is to stop the cliff-side wheel entirely and inch the other wheel forward until both sensors detect the cliff — then back up and turn 180°.

Sensor Mods and Arduino Upgrade

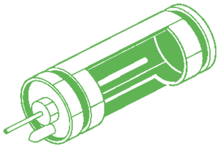
You can reconfigure the Tiny Wanderer sensors to face forward, for object avoidance, or run close together, for line following. Download the code for these behaviors at makeprojects.com/v/29.

We designed the Tiny Wanderer as a hackable platform. One possible modification is to add paper encoder disks (black/white stripes) inside the wheels, and use the IR sensors to track servo speed and perform dead reckoning calculations. And of course, you can also use different types of sensors, such as light, sound, or distance.

For a major upgrade of capabilities, the Tiny Wanderer's deck has mounting holes that fit a standard Arduino board, which has enough I/O pins to support all of the above — not to mention various plug-in shields with amazing capabilities. (I expect many Arduino-heads to be mainly interested in the Tiny Wanderer as an Arduino-scale rolling platform, and dispense with the whole ATtiny brain.)

If you're ever in Dallas, the DPRG meets every Tuesday night and every second Saturday of the month. Come visit!

Gregory Hayes



GEIGER COUNTER

This radiation detector clicks, flashes, logs radioactivity levels, and shares its data with the world.

By John Iovine

I've been designing, making, and selling Geiger counters for 15 years through my company, Images Scientific Instruments. They're fundamentally simple devices; you just need voltage high enough to run the Geiger-Müller (GM) tube. Anyone can design a counter that will work somewhat, but it's hard to make one that's reliable and long-lasting, because the electronics are so touchy.

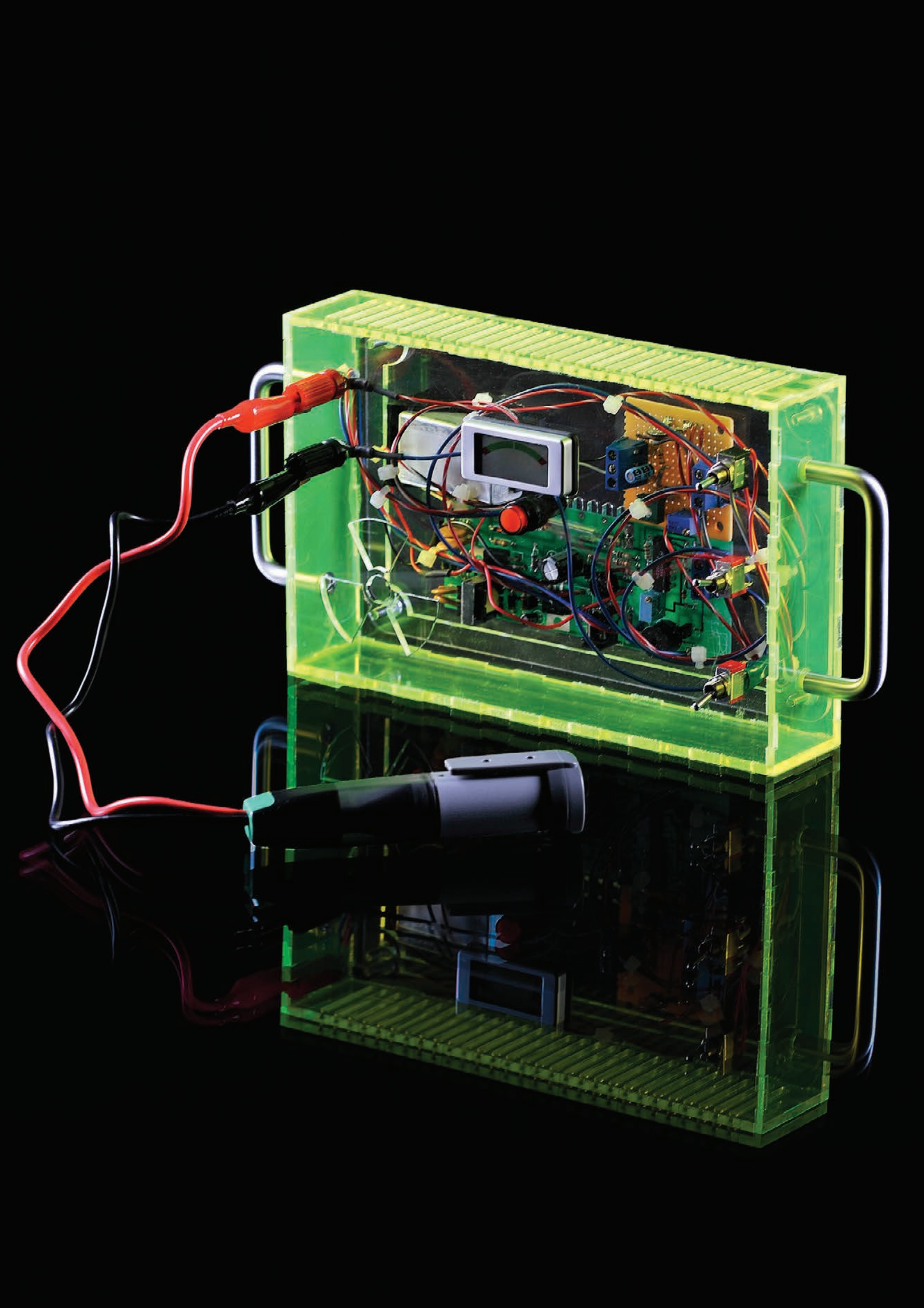
Last year I was redesigning my basic Geiger counter circuit when the earthquake, tsunami, and nuclear crisis hit Japan. We sold out immediately, and I was so swamped with orders that I had to put my improved design on hold. But I finally finished, and here it is.

You can easily configure this counter to use a variety of GM tubes. Not only will it output a click and an LED flash with each radioactive particle detected, you can also connect it to analog or digital radiation-level meters, a PC for plotting data, a portable SD-card data logger for placing somewhere without a computer, and a true random number generator. It's also compatible with the Radiation Network (radiationnetwork.com), so you can share your readings with others worldwide.

John Iovine is a science and electronics tinkerer and author who owns and operates Images SI Inc., a small science company. He resides in Staten Island, N.Y., with his wife and two children, their dog, Chansey, and their cat, Squeaks.

Gregory Hayes

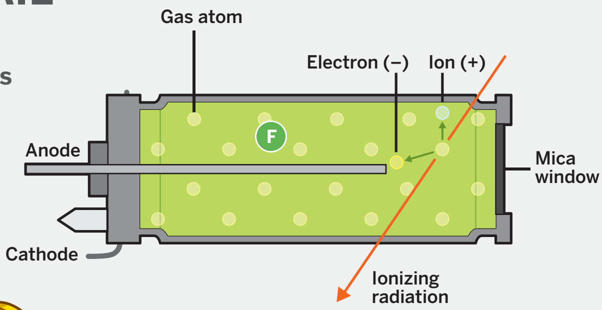
SET UP: p.103 | MAKE IT: p.104 | USE IT: p.110

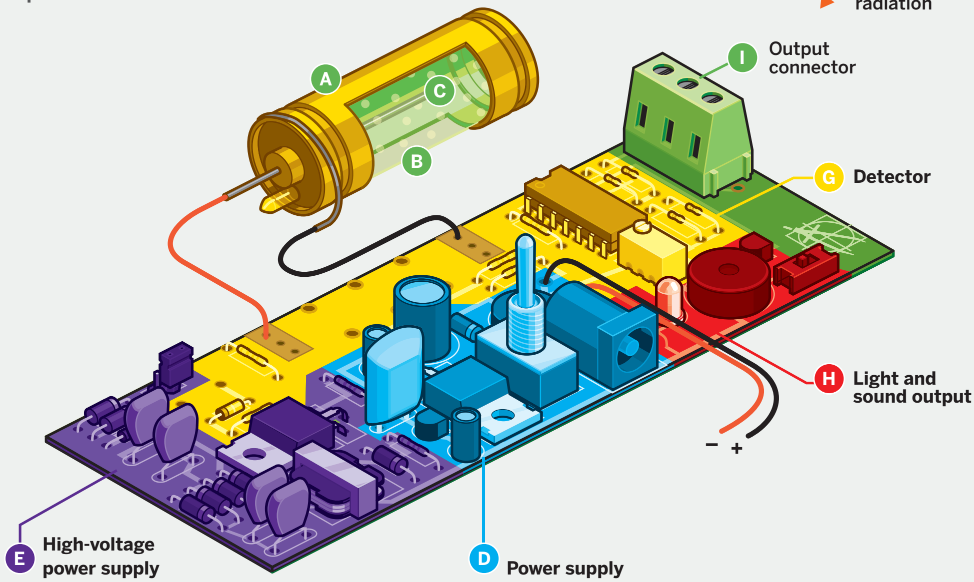


LOOKING FOR THE TRAIL

Radiation is emitted by the decay of unstable atoms. Geiger-Müller (GM) tubes detect 3 forms of this energy:

- α **ALPHA RADIATION** **Free-traveling helium nuclei, can penetrate a few sheets of paper.**
- β **BETA RADIATION** **Free-traveling electrons or positrons, can penetrate 3mm of aluminum.**
- γ **GAMMA RADIATION** **High-energy photons, can penetrate several centimeters of lead.**





A The **wall** of the GM tube is a cylinder of thin metal or conductor-coated glass. With metal cylinders, one end is mica, which (unlike metal) lets some alpha radiation through.

B The tube is sealed and filled with **halogen and noble gases**.

C An **electrode** runs through the middle of the tube.

D The **power supply** takes power from a 9V battery or 12V DC power plug.

E A **high-voltage power supply subcircuit** uses transistorized feedback with a step-up transformer to create a "ringing choke converter" that converts a 6V, 14.1kHz oscillation induced in the primary coil of the transformer into 325V across the secondary winding. A voltage multiplier boosts this voltage in steps up to about 600V DC. Three Zener diodes let you configure the output voltage to between 300V and 600V DC, to match the GM tube used.

F The high voltage is applied across the tube's wall and electrode, turning them into a cathode and anode, respectively. In the tube's normal resting state, the resistance between its anode and cathode is very high.

When a **radioactive particle** passes through the tube, it ionizes gas molecules in its path, which momentarily creates a **conductive trail** through the gas (like a vapor trail in a cloud chamber). This lowers the tube's resistance, in a momentary pulse.

G In the **detector subcircuit**, the tube's cathode directs the momentary pulse to the input of a comparator, alongside a reference voltage tunable by a potentiometer. The comparator cleans up each pulse by outputting a digital 1 while the tube output exceeds the reference voltage and a 0 when it's lower. This first comparator downstreams its output in parallel to the 3 other comparators on the same quad chip, which simply act as buffers.

H One downstream comparator feeds to the base of a transistor, which powers the **light and sound output** — an LED flash and speaker click — when each particle is detected.

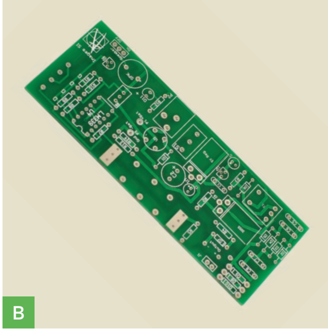
I The other 2 downstream comparators connect to an **output connector** for output to other devices.

After each detection, the high-voltage subcircuit takes some time to recharge the tube. During this "dead time" (which varies with different tubes; 90μs for an LND712), the instrument cannot make detections.

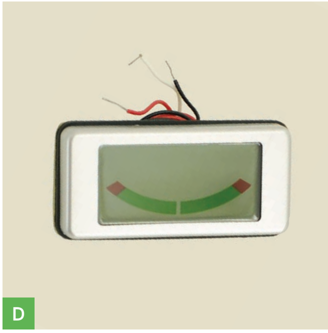
Rob Nance

SET UP.


A


B

C


D


E

MATERIALS

Get the Maker Shed kit (MKIS1) for a GMT-01 tube, PCB, and all electronics (except voltmeter, data logger, and batteries) at makershed.com, $170.

A. Geiger-Müller (GM) tube I recommend GMT-01 ($100), GMT-02 ($75), or GMT-06 ($50) from Images SI (imagesco.com). The GMT-01 is a U.S.-made LND 712 tube that detects all 3 radiation types.

B. Geiger Counter PCB Images SI item #PCB-52. You can also wire this circuit together on a plain breadboard.

C. Data logger (optional) Lascar Electronics EL-USB-5, item #2127048 from Jameco (jameco.com), $82

D. Voltmeter (optional, for analog meter), panel-mount display, 1V DC full scale Lascar Electronics EMA-1710, Jameco #2095082, $34

E. Radioactive source (optional) for testing. You can use uranium ore but a more reliable source is cesium-137, which comes in 5μCi (microcurie) and 10μCi plastic sample disks. See makeprojects.com/v/29 for sources.

» **Capacitors: 0.01μF, 1kV (4); 0.1μF (1); 10μF, 16V (2); 1,000μF, 16V (1)**
» **Diodes: 1N4007 (5); Schottky 1N5817 (1); Zener 100V 1N5271B and 200V 1N5318 (3 total, see Step 1a); Zener 5.1V (1)**
» **LED**
» **Power jack, 3.5mm DC, PJ108**
» **Transistors, NPN: 2N3904 (1), TIP3055 (1)**
» **Resistors, ¼W: 75Ω (1), 100Ω (1), 10kΩ (5), 100kΩ (1) , 1MΩ (2), 1.8MΩ (1)**
» **Resistors, ¼W: 470kΩ, 10MΩ** or other values dependent on GM tube used; see Step 1c.
» **Potentiometer, 1MΩ**
» **Switches: SPDT toggle (1), SPDT slide (1)**
» **Transformer, mini step-up** Images SI #HVT-03
» **Rectifier, 1.5A bridge, W01M, 100V**
» **Voltage regulator chips: LE33, TO92 package (1); MIC29405, TO220 package (1)**
» **Comparator chip, quad, LM339, DIP14 package**
» **Piezo speaker**
» **Socket, 14-pin DIP**
» **Terminal block, 3-contact screw** or 4-contact
» **Wire, insulated, 22 gauge stranded, red and black**
» **Battery, 9V**
» **Battery snap** for 9V battery
» **Fine metal screen (optional)** to protect GM tube mica window

For the data logger:
» **Battery, 9V**
» **Computer, Windows-based**
» **Software for graphing data sets** such as Microsoft Excel

For the analog meter, calibration, and enclosure:
» **Potentiometers: 47kΩ (1), 100kΩ (1), 500kΩ (1)**
» **Diode, 1N914**
» **Capacitor, 1μF**
» **Resistors: 100Ω (1), 390kΩ (1)**
» **Switches: SPDT toggles (2), SPST toggles (2)**
» **Perf board, small** I used half of a solderless-breadboard-matching board, RadioShack item #276-170, radioshack.com.
» **Ruler**
» **Small project box, plastic** or other non-metal enclosure, Mine measures 5.6"×3.2"×1.5". You can download a template for the laser-cut case on page 101 at makeprojects.com/v/29.
» **Machine screws, small, with matching nuts and washers**
» **High-speed rotary tool** e.g., Dremel, for cutting holes in plastic box

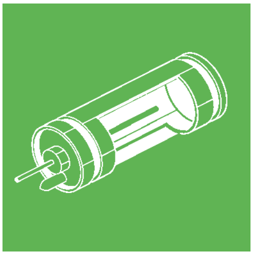
For the Digital Meter Adapter:
» **Digital Meter Adapter** (DMAD), Images SI #DMAD-3, $60 as kit or $90 assembled

TOOLS

» **Soldering equipment**
» **Multimeter**
» **Radiation Network software and cable (optional)** from radiationnetwork.com, $79

Gregory Hayes

MAKE IT.



BUILD YOUR GEIGER COUNTER

Time: A Weekend
Complexity: Moderate

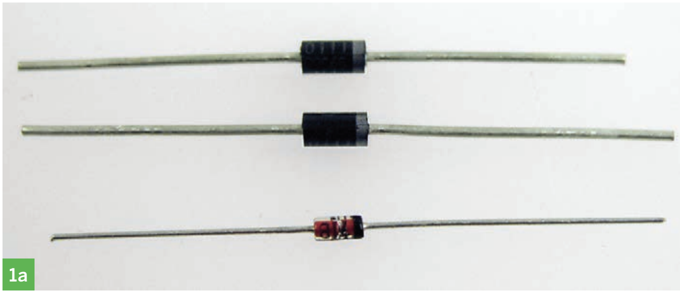
1. ASSEMBLE THE PCB

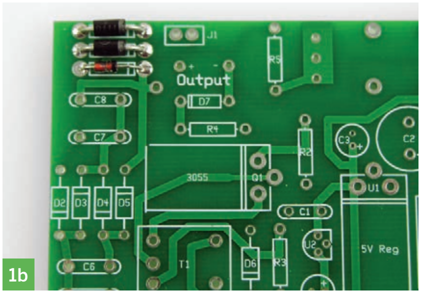
1a. From your GM tube's specifications, note the voltage required to drive it. This should be an even hundred number between 300 and 600 volts. Match this number by totaling the values of up to three 100V or 200V Zener diodes; for example, use two 200V Zeners and one 100V for a 500V tube.

1b. Solder the Zeners into positions D8–10 on the circuit board, following correct polarity. Fill D8 with a 100V Zener, if used. Nearby jumper J1 bypasses D8, which lets you quickly adjust the tube voltage down 100V.

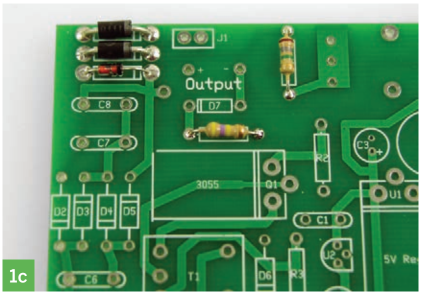
1c. Find the values for anode and cathode resistors R5 and R4 by referring to the specifications for your GM tube.

For the tubes I stock, the recommended anode resistor value ranges between 2.2MΩ and 10MΩ. The LND 712 tube shown in Step 2a needs a 10MΩ anode resistor and a 470KΩ cathode resistor. Solder resistors R5 and R4 where indicated on the PCB.


1a



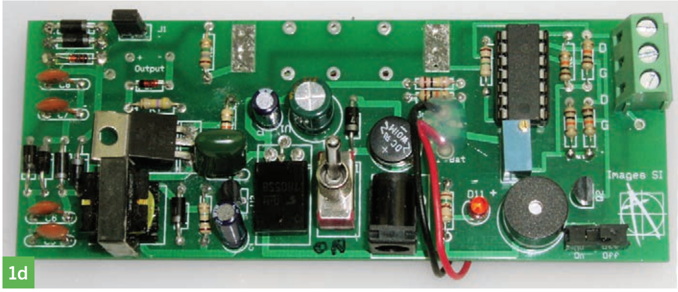
1b



1c

John Iovine

1d. Follow the silk-screened labels on the PCB (or the schematic diagram at makeprojects.com/v/29 if you're breadboarding) to place and solder all remaining components to the PCB. Be sure to orient all components with the proper polarity.



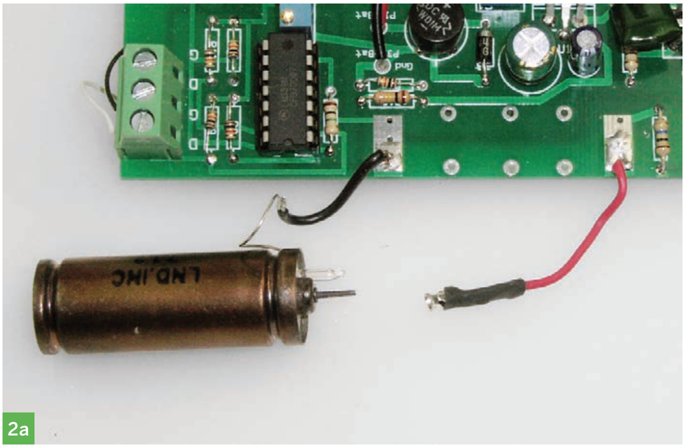
1d

2. ADD THE GM TUBE

2a. Identify the anode and cathode leads of your GM tube and connect them to the (+) and (–) tube terminals on the board, respectively; the anode (+) terminal is next to R5.

If you're using the LND 712 tube, you can unplug its center, anode (+) terminal before soldering it to a short wire and soldering the wire to the board.

On glass tubes, the cathode (–) is the end where a short wire extends from the metal cap along the outside of the tube (then penetrates inside).



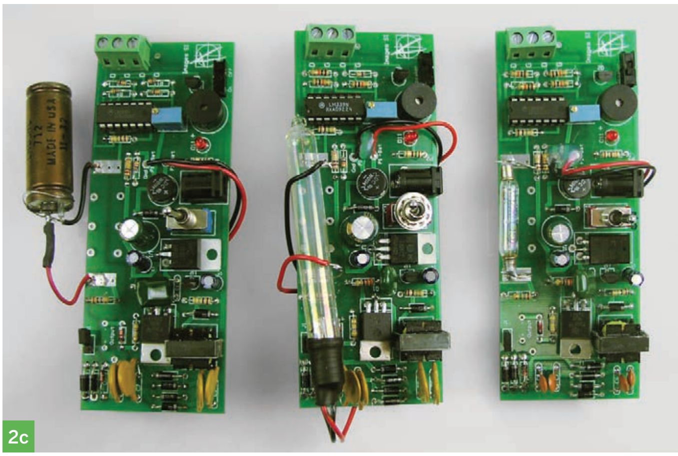
2a

2b. If your tube has a mica window at the end opposite the terminals, like the LND 712, install a fine mesh screen over it. This will protect the delicate mica while allowing alpha particles to pass.

2b

NOTEs: Heat from hot glue or a soldering iron might damage the GM tube.

2c. With a smaller tube, strap it down to the board with a few pieces of scrap wire, then dab on a small amount of glue or epoxy for added support. Take care if using hot glue, because heat can damage the GM tube.



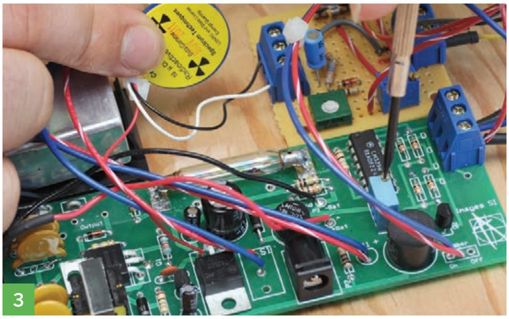
2c

3. TUNE THE COUNTER

Turn on the Geiger counter and if you have a radiation source, bring it close to the GM tube.

Now simply adjust potentiometer R6 until you hear clicking and see the LED blink. Each click and flash represents the detection of one alpha, beta, or gamma particle passing through the tube (but not all such events are detected; it depends on the tube's sensitivity).

Without a radiation source, background radiation from natural sources on Earth and cosmic rays will cause the Geiger counter to click. Where I live, background radiation triggers about 16 counts per minute (CPM) with an LND 712 tube.

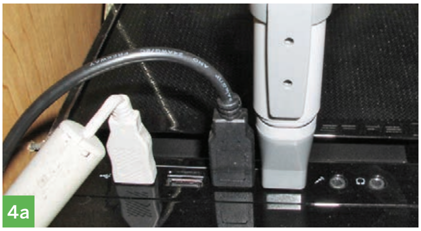

3

That's it — you've made a Geiger counter! The terminal block in the corner of the PCB has 2 pairs of output contacts for connecting to other devices: +3V–5V digital pulse signal (labeled "D" on the board) and ground (labeled "G").

STEPS 4 THROUGH 6 ARE OPTIONAL. They explain how you can connect your Geiger counter's output to a portable data logger, an analog meter, a digital display with serial output, and the Radiation Network, a public database that pools data from radiation monitoring stations worldwide.

4. CONNECT A DATA LOGGER

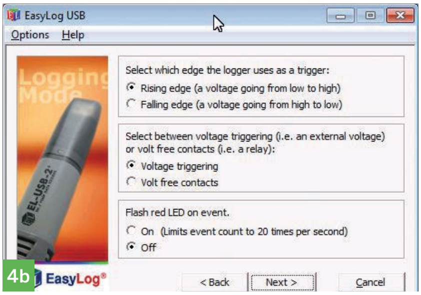
4a. Connect a 9V battery to the EL-USB-5 logger and plug the logger into a free USB port on your PC.


4a

NOTES: **For logging radiation data from the field with a small, portable setup, I've used the EL-USB-5 Data Logger from Lascar Electronics.**

You can also use a smart-phone with a data-logging application.

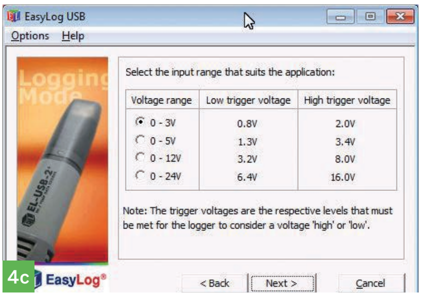
4b. Run the installation CD, and select the Set Up and Start option. In the Name/ Mode of Operation screen, select Count Events, and on the next screen, set the trigger to "Rising edge" voltage and the LED flash to Off.



4b

4c. For Voltage range, specify 0V–3V. The board outputs 4V–5V, but the data logger loads this output down to about 2.8V.

In the Time Period screen, choose 1 minute. Continue through the rest of the installation wizard, which is all self-explanatory.



4c

You can specify a different increment than 1 minute, but note that the logger can count up to 32,510 events per period, at a maximum data rate of 100 events per second (with the LED off).

Gregory Hayes (3)

4d. Connect the logger's 2 alligator clips to the counter's digital outputs, red to D (digital pulse) and black to G (ground). Cut and strip 2 short wire leads, screw them into the terminal block, and clip to the other ends.

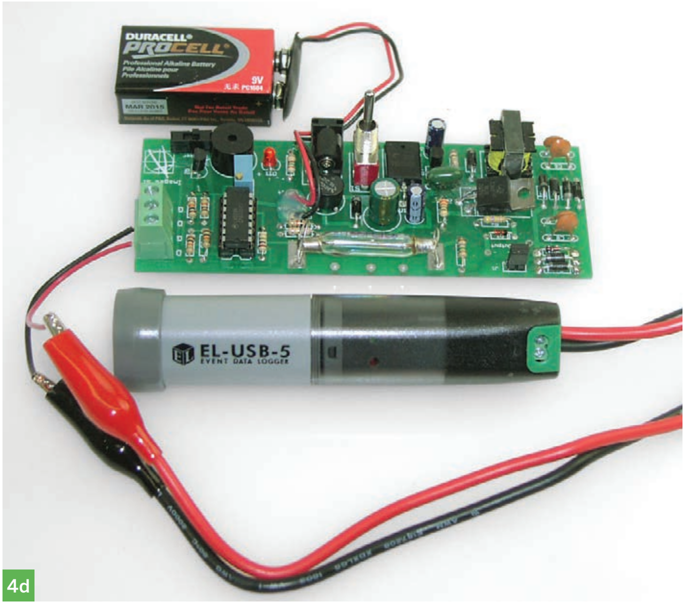
Now the logger is collecting data, and you can bring it wherever you want to take readings.

4e. Once your data is recorded, reconnect the logger to the computer via USB and save the data as a text file. You can then open the data file in Microsoft Excel and use the Chart Tools to graph and manipulate it in various ways. The image here shows 298 minutes of background radiation data graphed by CPM, which averaged at around 16.

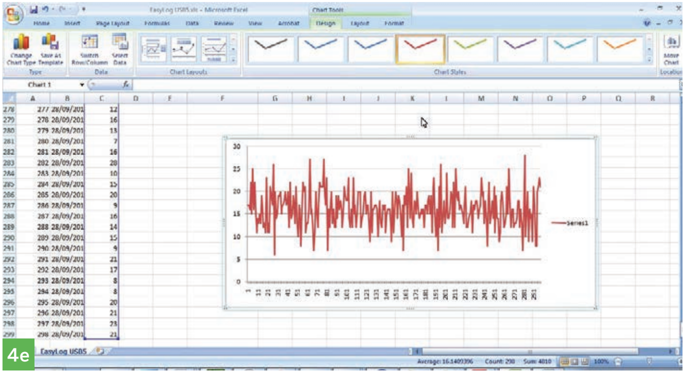
5. ADD AN ANALOG DISPLAY

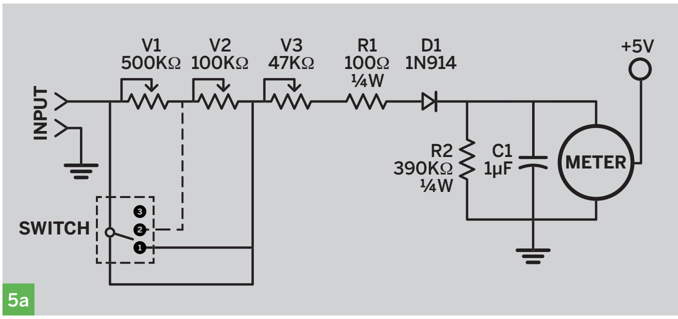
Adding an analog meter lets the counter display the current radiation intensity. This circuit is toggle-switchable to display 3 reading ranges, up to 1, 10, or 100 milliroentgens per hour (mR/hr).

5a. On a small circuit board, assemble the circuit as shown here.



4d


4e



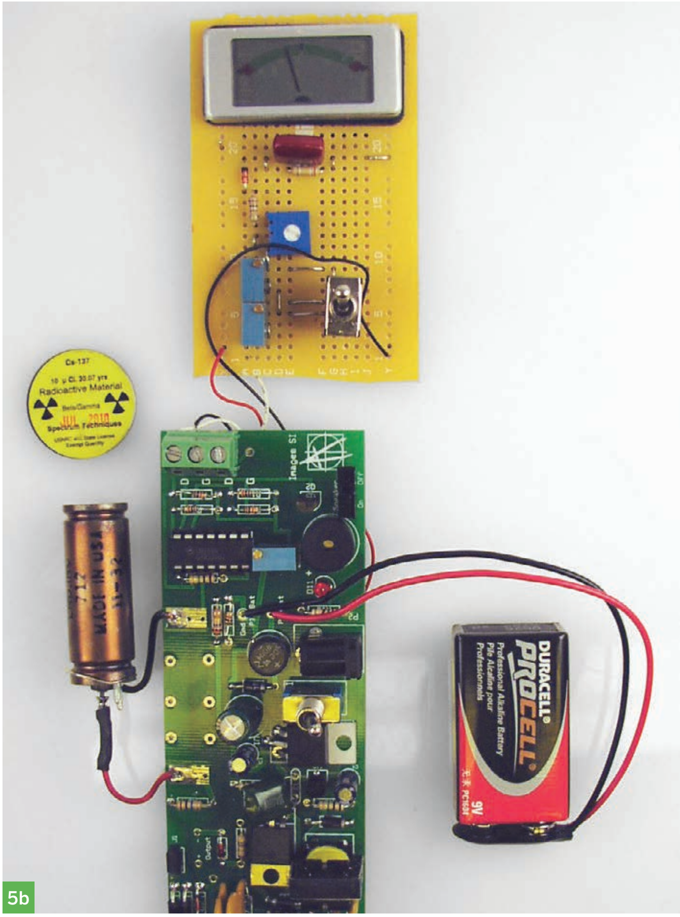
5a

Damien Scogin (5a)

5b. Wire the counter board's digital output and ground from the terminal block to the meter circuit's inputs. Also connect the (–) terminal of the meter itself to ground. For the +5V needed to power the analog meter, connect it to any +5V contact on the counter PCB, such as the +5V side of the speaker or of the power jack (you can refer to the schematic or just eyeball the PCB).

5c. To get a ballpark calibration for the meter (with some GM tubes), we can use a 10μCi cesium-137 sample disk. The chart below shows how far to hold the disk away from the tube to expose it to approximate radiation levels of 1, 10, and 100mR/hr. With the toggle switch in position 1, use a small screwdriver to adjust potentiometer V3 so that the meter reads full scale when the disk is at the distance listed in the table. Flick the switch and move the sample to the second distance for adjusting potentiometer V2 to full scale, then do the same for pot V1.

For tubes like the GMT-01, which detect alpha particles through a mica end window, position the source facing the end. For other tubes, position the source facing the middle of the tube.

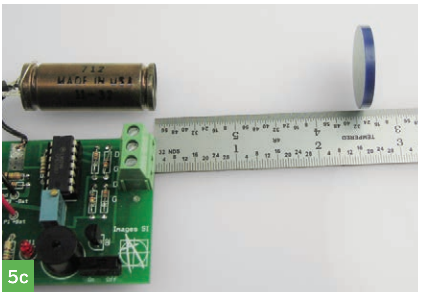


5b

Analog Meter Calibration Table

GM Tube	GMT-01 (LND 712)	GMT-02	GMT-06
1mR/hr (pot V3)	6"	6.5"	0.5"
10mR/hr (pot V2)	2.5"	1.6"	0.25"
100mR/hr (pot V1)	0.5"	0.25"	(unknown)

These values are all approximate, as will be your calibration. **Your tube's response can vary +/– 20% from the tubes I used to write the table here. The strength of your radioactive source and the behavior of your electronic components can also vary, and all these factors affect accuracy.**



5c

5c

6. ADD AN ENCLOSURE

6a. Remove the power switch (S1) and the speaker on/off slide switch (S2) from the counter PCB, replace the slide with another toggle, and wire the 2 toggles offboard using 6" lengths of wire.

6b. If you added an analog meter, also remove its SPDT toggle switch and connect it offboard with wire leads.

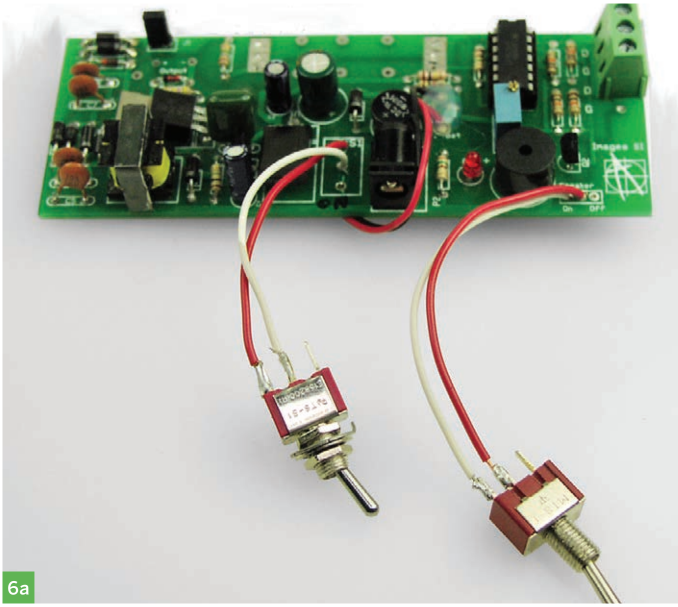
6c. Use a Dremel or other tool to cut holes in the enclosure's front panel for mounting the toggles and the meter, if used.

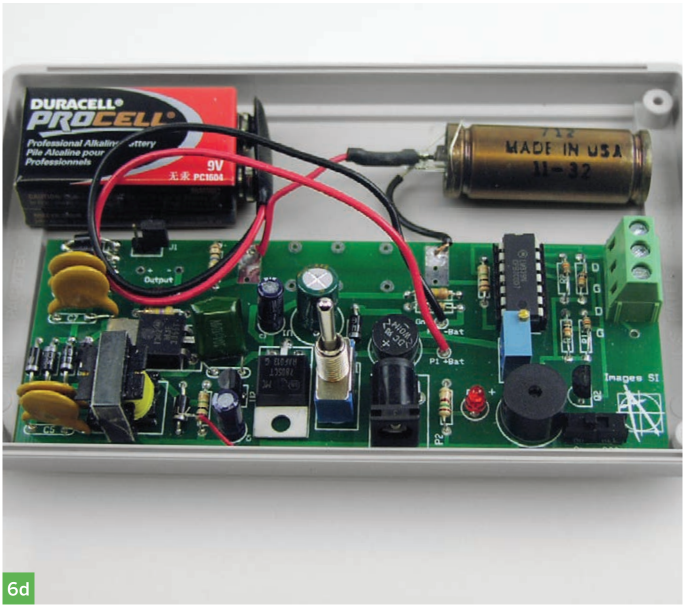
If you're using the GMT-01 or another tube with a window for alpha particles, cut a matching window in the side of the enclosure.

6d. Mount the toggle and meter (if used) to the front panel. Secure the circuitry and tube inside using your preferred method.

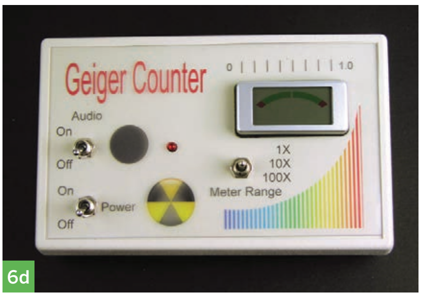
For the PCB, you can drill holes in the board and lash it down inside the case using insulated wire anchored around machine screws, washers, and nuts.

For the GM tube, run 4 machine screws longer than the tube's diameter up through the bottom of the case to surround the tube, secure the screws with washers and nuts, and lash the tube underneath with wire. Align the tube to its window if it has one. Enjoy your new Geiger counter!


6a



6d



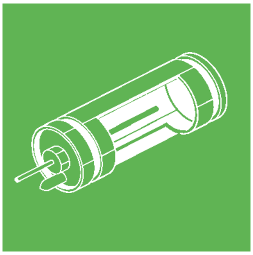
6d

NOTES: The plastic will not block much beta or gamma radiation.

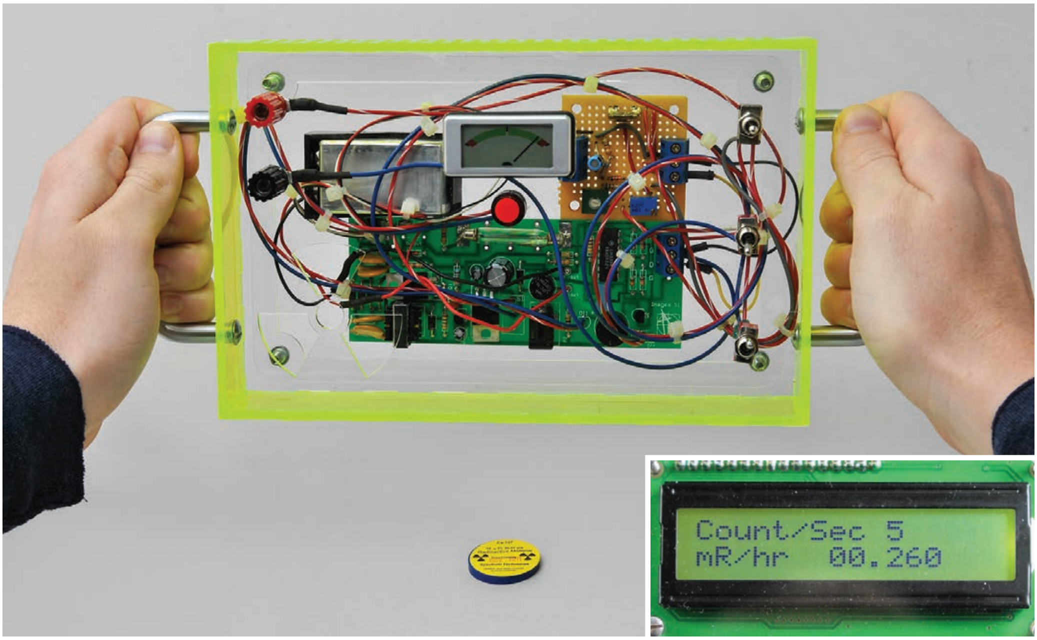
Label the panel components and decorate the enclosure as desired.

TEST BUILDERS:
Brian Melani and Dan Spangler, MAKE Labs

USE IT.



THE HIDDEN LANDSCAPE OF RADIOACTIVITY



Gregory Hayes; John Iovine (inset)

Test for Radioactive Contamination

If you're testing for contamination, your GM tube should be sensitive to alpha radiation as well as beta and gamma (like the GMT-01).

Geiger counters can only test for gross levels of contamination that show up clearly above background radiation; they are not the proper instruments for detecting low-level contamination. That said, here is how to test for radioactive levels above background:

1. Establish the background radiation level by measuring CPM for at least 20 minutes, and longer is better. Note the lowest and highest levels and then average them all to establish the baseline minimum, maximum, and average. With my data from Step 4, a 298-minute sample, my average CPM was 16, and min to max was 6 to 28.

2. Position the GM tube very close to the top surface of the material you're testing, and run the counter, recording the CPM output. The longer the run, the more accurate the results.

3. Compare the radiation output of your sample against your baseline.

Alternative Sound Output

If you want louder clicks from your Geiger counter, you can use the alternative sound output circuit; see the schematic at makeprojects.com/v/29. In this circuit, the pulse signal from the comparator triggers a 555 timer chip, which is set up in monostable mode to stretch out the pulse it receives on

The Author and Publisher do not make any warranties (express or implied) about the radiation information provided here for your use. All information provided should be considered experimental. Safety and health issues and concerns involving radioactive contamination should be addressed, confirmed, and verified with local and national government organizations or recognized experts in this field.

its trigger. The output pulse from the timer flashes the LED and outputs an audible click to the speaker via pin 3.

The alternative circuit's components (555 chip, caps, resistors) fit on a small breadboard. You can connect it to one of the main board's digital outputs, or to where the standard light and sound output connects (LM339 pin 14), either replacing the original output or making it switchable.

Digital Meter Adapter

You can do more with your Geiger counter by wiring its digital output to a standard 3.5mm mono earphone jack, connecting ground to the sleeve contact and signal to the tip.

This output jack lets you connect the meter to my company's Digital Meter Adapter (DMAD) an add-on that shows CPM or counts per second (CPS) along with milliroentgens per hour (mR/hr). Onboard switches also configure the adapter to work as a true random number generator, with multiple ranges. The DMAD (see inset, opposite) has a second 3.5mm plug for output, which lets you connect any of its output functions to a computer via 3.5mm to RS-232 serial cable.

Radiation Network

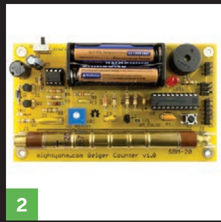
Want to help keep track of radiation levels nationwide? A 3.5mm output jack, as connected to the Digital Meter Adapter above, will also let your Geiger counter become a monitoring station for the Radiation Network (radiationnetwork.com), home of the National Radiation Map. The network software is sold with an adapter cable ($79 together).

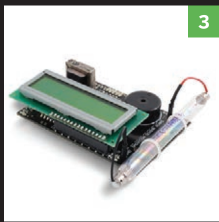
For schematics and a template for an acrylic enclosure, see makeprojects.com/v/29.

Juan Peña (Sparkfun)

More DIY Geiger Counters

By Paul Spinrad





1. USB Geiger Counter

SparkFun Electronics, $150
sparkfun.com
Has an onboard ATMega328 microcontroller and a U.S.-made LND 712 Geiger tube (Figure 2b, page 105) that detects alpha, beta, and gamma radiation.

2. MightyOhm Geiger Counter Kit

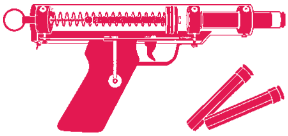
Maker Shed, $100
makershed.com MKMO1
Solder-it-yourself kit includes ATtiny2313 microcontroller and Russian-made SBM-20 Geiger tube that detects beta and gamma.

3. Radiation Sensor Board for Arduino, with Geiger Tube

Libelium, €115 ($163)
cooking-hacks.com
Currently includes China-made J305β GM tube that detects beta and gamma, but the board works with any tube in the 400V–1,000V range.

4. Grove Geiger Counter Module

Seeed Studio, $27 without GM tube
seeedstudio.com
Works with Seeed's $16 China-made J408γ Geiger tube, which only detects gamma radiation, or you can use any other 400V tube.



BETTER NERF GUN

Build a metal foam-dart gun that blows away store-bought plastic models.

By Simon Jansen

Like most geek-filled offices, at my workplace we have several Nerf guns and similar toy weapons floating about. Not impressed with the performance of my colleague Lester's Nerf Maverick, a mainstay of Nerf's suction-cup-dart-firing "N-Strike" series, I decided to build a better Nerf gun myself.

Here's the result: a simple weapon, single shot only, but with much greater range and accuracy than the standard toys. Let your indoor combat foes tremble; with a little practice, one shot is all you need.

I made the pistol from PVC pipe, aluminum extrusion, and aluminum tubing, with wood for the grip and various pieces of metal and plastic, mostly from my junk box — and you can easily adapt the design to use what you have in yours. A sliding trigger and telescoping plunger keep the pistol short and compact. You'll need a small metal lathe to machine some of the parts, but as there's nothing too critical in the design, this is a nice project to hone your skills.

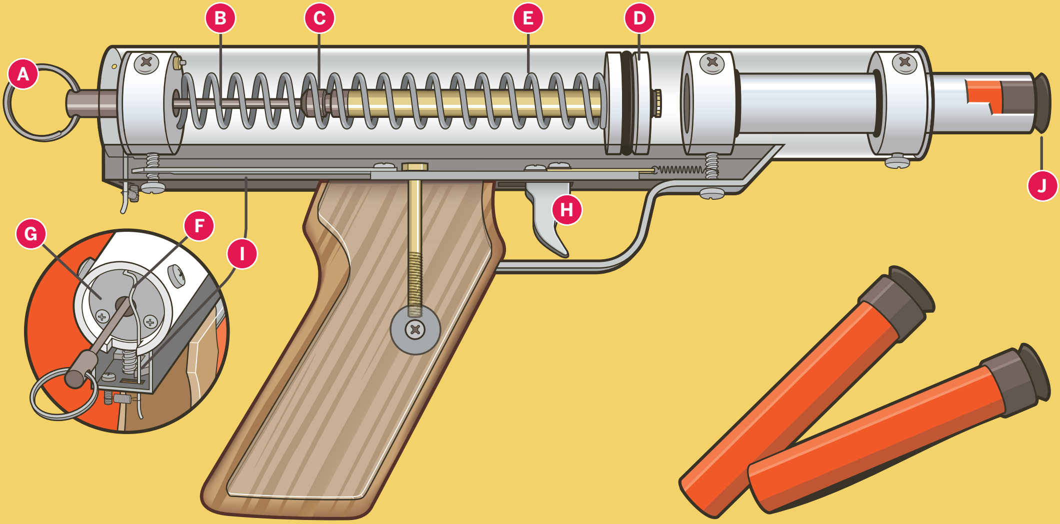
Simon Jansen is a New Zealander with more than a touch of the eccentric Englishman. A software engineer by trade, he likes building all manner of odd inventions and restoring old cars in his spare time.

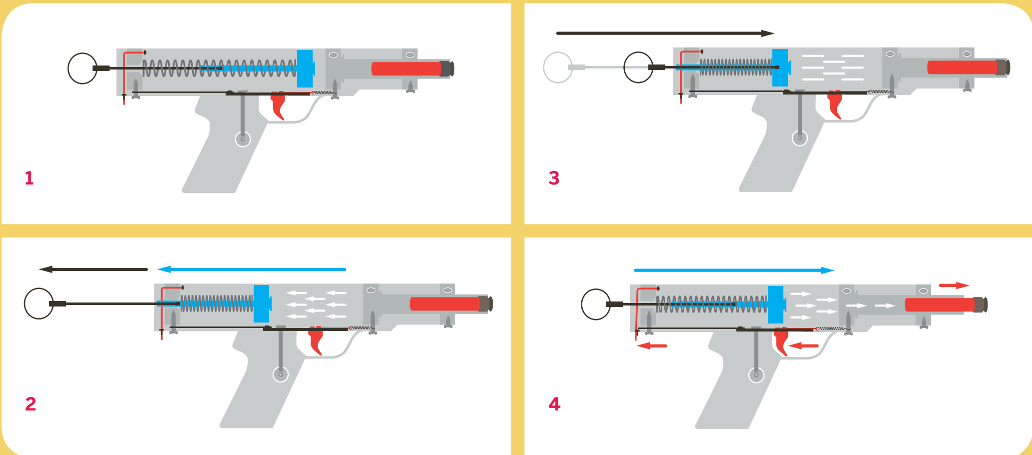
SET UP: p.115 | MAKE IT: p.116 | USE IT: p.122

Gregory Hayes

SECRETS OF THE CHAMBER

Some dart guns propel a round by pushing it directly with an expanding compression spring. Like higher-end commercial Nerf guns, this weapon uses a spring-loaded piston to compress air in a large chamber behind the dart, blowing it out of the close-fitting barrel. This design lets a larger spring power the dart, and with a long barrel, it also allows the dart more time to accelerate before flight.





1. To cock the gun, the user pulls back the **A ring**. This slides the telescoping plunger's **B inner rod** back until its inner stop hits the inner rod **C catch piece**.

2. Further pulling draws the **D piston** back against the **E compression spring**, until the **F catch wire** clicks sideways into a groove in the catch piece, holding the piston back in its cocked position.

3. The user may then push the ring back in, telescoping the plunger rod foward again, with the pull ring just behind the **G end cap**.

4. Pulling the **H trigger** causes a **I sliding plate** to release the catch wire. The piston leaps forward and propels the **J Nerf dart** with air pressure squeezed from the chamber into the narrower barrel, rather than through direct spring action.

Timmy Kucynda

SET UP.

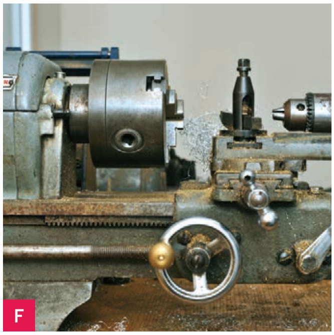

A


B


C


D


E


F

Gregory Hayes

MATERIALS

For metal parts, you can use steel, aluminum, brass, or copper, depending on what's available and what kind of look and feel you want.

A. Plastic Pipe
- **PVC pipe, Schedule 40, 1¼" ID × 1' length**
- **PVC or HDPE pipe, Schedule 80, ½" ID × 6"**

B. U-channel stock, aluminum, 1.5mm thick × 22mm base × 12mm legs, 1' length or 1⁄16"×7⁄8"×½"

C. Metal tubes and rods
- **Tube, metal, 1" OD × 1'** Different pipe diameters will work for the barrel, but you'll have to adapt them differently to fit the dart.
- **Tube, metal, 5⁄16" OD × 1'**
- **Rod, metal, ⅛"×1'** like from an old printer or scanner
- **Rod, metal, 5⁄16" diameter, a few inches long** or similar stock, for machining the catch piece and the rear stop

D. Springs
- **Compression spring, 0.7" diameter × 6" long, 6.2lbs/in** item #364 from Century Spring (centuryspring.com), or similar size and spring constant
- **Coil spring, about 1" long** like from a click pen, printer, scanner, toy, or similar — for trigger return
- **Coil spring, about ½" long** like from a printer, scanner, or disposable lighter — for catch mechanism

E. O-rings and clips
- **O-rings, rubber, 1⅛" OD, ⅞" ID (2)**
- **C-clips, 1" ID (2)** aka external retaining rings or "circlips", to fit your barrel

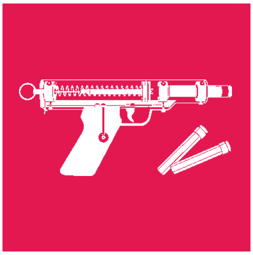
- **Metal strips, 1⁄64" (0.015") thick × ¼" × 4"** to attach the trigger return spring to the trigger
- **Aluminum flat bar, 3mm×20mm×1' length** for the trigger plate
- **Aluminum flat bar or sheet, 1mm×20mm×1' length** for the trigger ramp and trigger guard
- **Pull ring, about 1" ID** big enough to put a finger through
- **Music wire, 1.58mm (0.062"), about 1' length** You need 4", but expect some trial and error.
- **Cutting board, plastic, ½" or thicker**
- **Wood scrap, about 1" thick** enough to make a pistol grip
- **Acrylic scrap, ¼" thick** enough to cover both sides of grip
- **Fender washer, 8mm ID × 32mm OD**
- **Bolt, 6mm**
- **Machine screws, 3mm (7)**
- **Screws, self-tapping, short (7)** Mine had 7mm threads, 10mm total length.
- **Screws, self-tapping, long (2)** Mine had 18mm threads, 22mm length.
- **Screw, short and wide** for holding the plunger onto the rod. I used a bookbinding screw.
- **Metal, assorted scraps** for machining small parts. I made a 10mm-thick aluminum trigger, a 16mm (⅝") cylindrical steel insert for the handgrip, a ½" round piston stop from scrap brass sheet, and a 3⁄16" internal stop from a scrap of steel.

TOOLS

F. Metal lathe

- **Soldering torch and solder** I used a little butane blowtorch, about the thickness of a marker, that I got from my local auto parts store.
- **Drill and drill bits**
- **Countersinking bit**
- **Taps: 3mm, 6mm**
- **Files, small**
- **Hacksaw, screwdriver, pliers, ruler, and pencil**

MAKE IT.



BUILD YOUR NERF GUN

Time: A Weekend
Complexity: Moderate

1. BARREL, BODY, AND END CAP

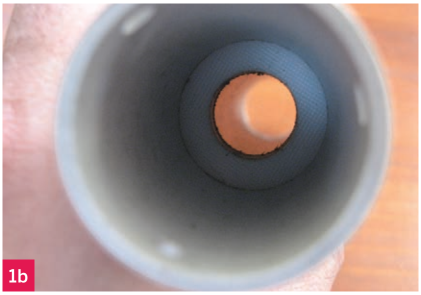
1a. For the body, cut a length of 1¼" PVC pipe with a hacksaw.

1b. From the cutting board, cut 2 plastic centering rings to hold the barrel. I finished them on a lathe and secured each one into the body using 3 screws.

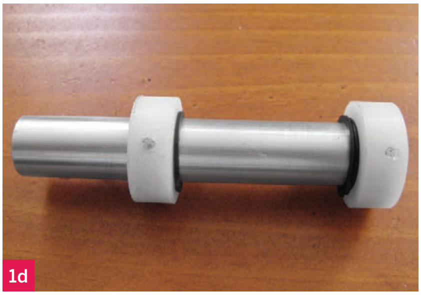
1c. Cut the barrel out of 1" metal tube. It can be any length over 70mm (the length of a Nerf dart), and can protrude any amount from the body, depending on the aesthetics you want.

1d. Machine 2 grooves into the barrel so that C-clips can hold it between the rings. Leave room for a rubber O-ring against the rear ring. The clips prevent the barrel from sliding, and the rubber ring keeps it from rattling or rotating.

1e. A standard ½"-diameter Nerf dart should fit snugly inside the barrel without binding. To fine-tune your barrel's inside diameter, cut an inner sleeve from ½" ID plastic pipe, and lathe it down to push-fit inside the barrel.


1b


1d


1d


1e

I made this design up as I went along, without working out the dimensions ahead of time. You can do the same, or download templates from my build at makeprojects.com/v/29.

TIPS: To mark a square line around a pipe, wrap a piece of paper around it.

Cutting boards are a good source of plastic for projects — it's cheaper and easier to go to a supermarket than buy from an industrial plastics supplier.

NOTE: The Nerf dart's suction-cup tip is a bit wider than its shaft, so the plastic sleeve stops 20mm short of the barrel's end. This lets the dart sit inside the barrel completely when the gun is cocked, with no friction against the barrel.

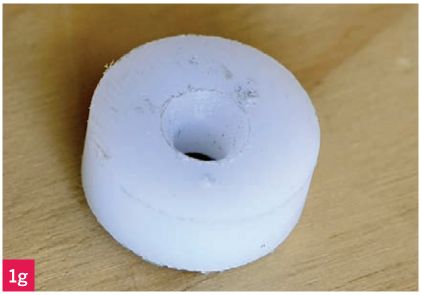
Simon Jansen

1f. Mark and drill 3 equidistant screw holes in the body for each ring, without the rings inside. Then slide in the barrel assembly, mark the rings through the holes, and drill them with small holes for the self-tapping screws.


1f

NOTES: Later you'll install a longer bottom screw in the rear centering ring.

1g. Machine the end cap from cutting-board plastic to fit snugly inside the body. Drill a centered 8mm hole in the cap for the plunger to pass through, and chamfer the front with a countersink bit to let it exit easily. Mount an 8mm fender washer onto its back using 2 small screws.


1g

The washer provides a hard-wearing metal surface for the catch wire to slide against.

1h. For the catch wire, cut 4" of the 1.2mm wire. Drill and thread it through the end cap and washer. Bend the front of the wire, or attach a small stop, so it won't pull out. Bend the back of the wire to lie flush across the end cap.

Drill and mount the end cap in the body the same way you did with the centering rings.


1h


1h

TIP: Old printers and scanners are a great source of small-diameter steel rods that machine well.

2. PISTON AND PLUNGER

2a. Machine the piston out of more cutting-board plastic to slide within the body. Cut an O-ring groove around its perimeter to provide a seal.

The telescoping plunger is made from a 96mm-long 5⁄16" tube. A short, wide screw holds it to the piston. I soldered mine, but you can also tap threads in the tube and screw it in. A small O-ring under the screw helps seal the piston.


2a


2a

Gregory Hayes (1g, 2a top)

2b. For the telescoping section, cut a ⅛" rod, 115mm-long, and solder a 5⁄16"-diameter cylindrical stop on back.

2c. For the rear stop, cut an 18mm length of 5⁄16" rod and face off the ends. Drill a ⅛" hole halfway through the cylinder from one end; this is where you'll solder in the ⅛" rod. Drill a hole across the stop 3mm from the other end for attaching the pull ring.

2d. Machine the catch piece from 5⁄16" rod, about 25mm long and with a ⅛" hole for sliding over the ⅛" rod. Grind down about 10mm of the front end so it fits tightly into the 5⁄16" tube, and chamfer the back so it will pull through the end cap.

2e. Machine a square groove 7mm up from the back, just wide and deep enough to hold the catch wire.

2f. Slide the catch piece over the ⅛" rod, and then solder a stop, 3⁄16"-diameter or so, onto the rod's front end.

2g. Slide the rod into the tube and solder on its catch piece.

3. MAIN SPRING AND TEST-FIRING

3a. Remove the pull ring, slide the spring and end cap over the plunger, and replace the ring. Slide the assembly into the body. Cut a notch in the back of the body to let the catch wire swing side to side.


2b

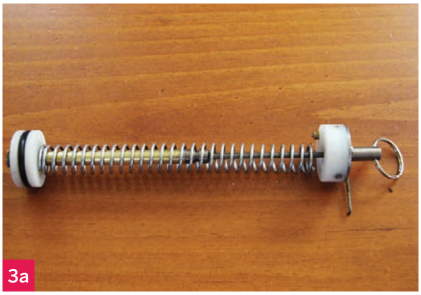

2c–2d


2f


2g

NOTES: The catch wire in this groove is what holds the plunger back once the pistol is cocked.

This smaller stop slides inside the 5⁄16" tube; make it a loose fit so the internal stop can move freely.


3a


3a

Gregory Hayes (2b–2f)

3b. With the end cap screwed into place with its 2 top screws (you'll add the bottom screw later), test-pull the plunger back until the rod telescopes back and you can swing the wire into the catch piece.

Once the gun is cocked, you can telescope the rod back in, flush with the end.

To test fire, just push the wire sideways out of its notch.

4. TRIGGER SYSTEM

4a. Cut and file a trigger from 10mm-thick aluminum, and tap 2 mounting holes on top.

Cut and file a trigger plate from 3mm aluminum to slide within the housing. Drill 2 mounting holes in front for the trigger and 2 in back for the ramp. In the middle, 46mm from the trigger end, cut a 19mm×8mm slot for the bolt that holds the handgrip.

4b. Cut the ramp out of 1mm metal 85mm long, with a 35° wedge in back to push the catch wire. Screw the ramp to the trigger plate.

4c. Make the trigger housing from U-channel 22mm×210mm long, undercut 45° in front. Two holes let it screw-mount to the centering rings through the body, and another hole takes the bolt that holds the grip. A 10mm×22mm slot lets the trigger pass through.


3b


3b

NOTES: The trigger plate and ramp could be a single piece, but as this was my prototype, I made them separate so I could fine-tune the ramp angle.

One trigger mounting screw also holds a tab that the trigger return spring hooks onto.

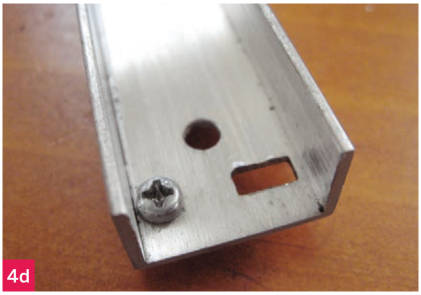

4a


4b


4c

By varying the angle of the ramp, you can adjust how sensitive the trigger is; the steeper the ramp, the more sensitive the trigger.

4d. On back of the housing, tap a small hole on the left for the screw anchoring the catch-wire spring, and cut a slot on the right to let the catch wire pass through.


4d

5. GRIP AND TRIGGER GUARD

5a. Cut the grip out of 18mm-thick wood. Drill a 16mm hole crossways through the grip, to hold a cylindrical metal insert. Then drill a 6mm hole from the top of the grip to the middle of the insert, for the long bolt that secures the grip to the trigger housing.


5a

5b. Cut the 16mm cylindrical metal insert. Tap a 6mm hole in its side, for the bolt, and tap a centered 3mm hole into each face, for screwing on 2 grip side plates.


5b

5c. Cut side plates matching the grip out of 4mm acrylic, then file and sand them into a comfortable shape. File a step into the tops of the plates so that they fit snugly over the sides of the trigger housing.


5c

NOTE: The step in the top of the acrylic plates keeps the grip from rotating under the housing, and also prevents the side plates from rotating on the grip.

5d. Cut and bend a trigger guard from thin aluminum plate, about 1mm thick. Angle its front end up to cover the front of the trigger housing and abut the round pistol body. The back of the trigger guard pushes into a shallow hole drilled into the front of the grip.


5d

TIP: To make the trigger guard front fit against the body tube, I wrapped sandpaper around the tube and rubbed the aluminum guard against it until it had the matching concave shape.

6. FINAL ASSEMBLY

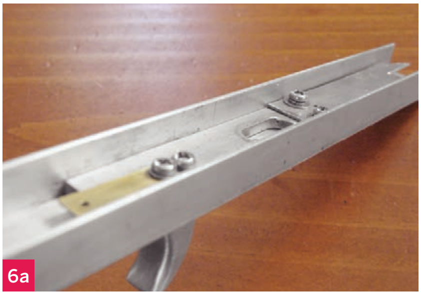
6a. Attach the trigger to its plate using two 3mm screws, sandwiching the brass tab for the return spring under the front one. Screw the ramp to the rear of the plate, and drop the assembly into the housing.

6b. Run the trigger housing's front mounting screw up through its hole, and then hook the trigger return spring between it and the trigger plate tab. The spring will hold the mounting screw in place until you screw it into the gun body.

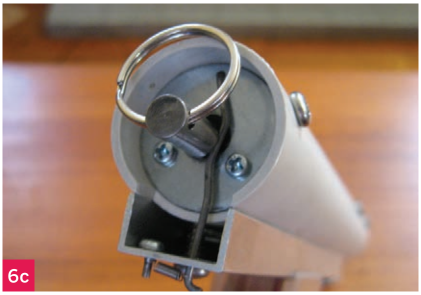
Run the 6mm bolt through the spacer and its slot in the trigger plate. Push the steel insert through the grip with its threads aligned with the mounting hole for the long bolt, then screw the bolt into the insert through the grip. Screw the acrylic plates onto each side.

6c. Finally, screw the grip and trigger assembly to the main body of the pistol using the 2 long, self-tapping screws, making sure the catch wire passes through the rectangular slot in the trigger housing. Loop the ½" spring between the end of the catch wire and the small screw next door, to pull the catch wire in toward the plunger rod.

Congratulations! Your pistol is fully assembled.


6a


6b


6c

NOTES: The top of the bolt is threaded through a small spacer cut from 5⁄16" tube (see photo 5b) so that it doesn't interfere with the sliding trigger plate. And I ground the head of the bolt down so that it would clear the body piece when the pistol was assembled.

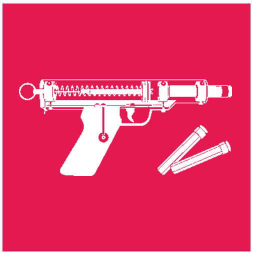

6c

With the trigger housing attached to the body and the catch spring in place, you can see how pulling the trigger will release the catch wire.


6c

TEST BUILDER: Nicholas Raymond, MAKE Labs

USE IT.



FIRE AT WILL

Using the pistol is simple. You pull back on the ring on the end of the plunger until the catch wire hooks onto the plunger catch. Then simply push the telescoping part of the plunger back into the pistol. (With a non-telescoping plunger, the pistol would have to be longer and wouldn't be as neat when cocked.) You're ready to fire!

I've found that when fired over a range of 8–10 meters (26–33 feet), the darts are fairly accurate and travel fairly flat. At farther distances, you need to start lifting the barrel to get more of a lob trajectory on the darts.

What else could be done? You can paint the pistol any way you want, although I would stay away from black, so it isn't mistaken for a real weapon. Most parts of the pistol can be modified to suit your own particular tastes. The grip can be changed, the barrel length modified. Adding a stronger main spring is probably the best way to increase the range. You could also add some kind of sight — perhaps even a laser sight from a cheap laser pointer, for that high-tech touch.

The next version I'm planning is a Nerf-firing replica of a "real" prop weapon. Perhaps a stormtrooper's blaster from *Star Wars* or a pistol from *Blake's 7*?

Gregory Hayes

1+2+3 High-Pressure Foam Rocket

BY RICK SCHERTLE

You can make it!

CALLING A ROCKET THAT SPRINTS OVER 100 feet into the air a "toy" might be a bit of a stretch. Toy or not, this rocket really packs a punch. Fly it using the Compressed Air Rocket launcher from MAKE Volume 15 (makeprojects.com/project/c/585; get the kit at makezine.com/go/launcherkit) or a stomp rocket launcher (makezine.com/go/stomplauncher).

YOU WILL NEED

Foam pipe insulation, ½" inside diameter You can build 8 rockets with a 6' piece (instructions here are for one rocket).
Foam sheet, 2mm thick, 9"×12" available at craft stores or online
Zip tie, 8"
Duct tape Fun colors are now available.
Scissors
Hot glue gun and glue
Packing tape, clear (optional)

1. Cut the foam and cinch with a zip tie.

Cut a 9" section of foam pipe insulation. Wrap the zip tie ½" from one end and cinch it tight so no air will escape. Trim the excess foam above the cinched-off end.

2. Apply duct tape to foam rocket body.

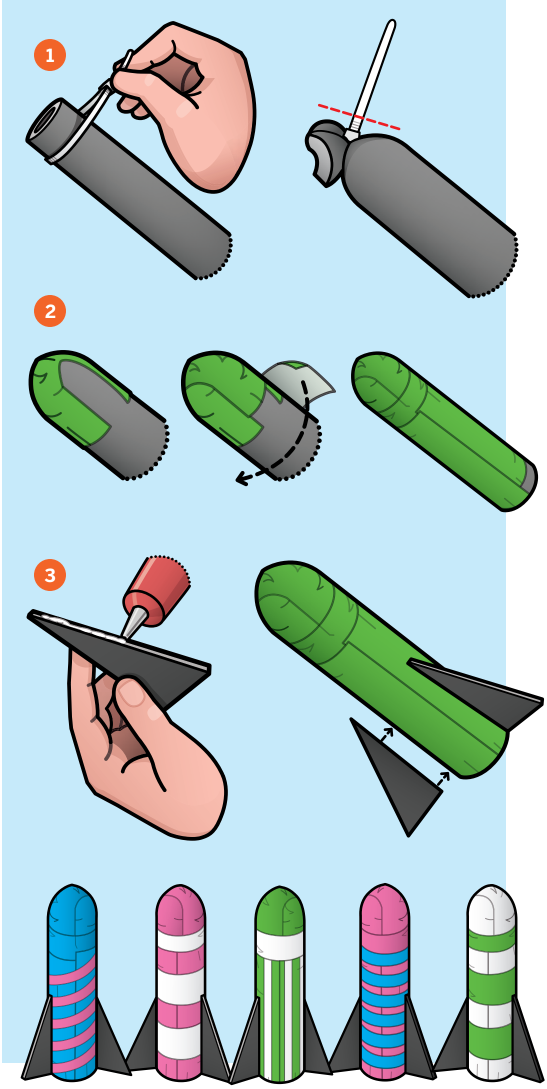
Criss-cross 2 pieces of duct tape over the cinched end. Now cover the entire foam section with duct tape spanning the length. Three overlapping pieces of tape should do the trick.

3. Cut and attach foam fins.

Cut a 4"×1½" rectangle from the foam sheet, then cut it diagonally to make 2 fins. Repeat. Using generous amounts of hot glue, attach 3 of the fins, spaced evenly, onto the foam rocket body tube. If the glue doesn't stick well to the rough duct tape, wrap 2 strips of clear packing tape over the duct tape around the bottom of the rocket to create a smooth surface for gluing the fins.

Use It

Pressurize the compressed air launcher for 45psi–65psi, and launch. (For a lower pressure/altitude launch, use a stomp launcher.) When the duct tape finally fails with a spectacular blowout, just apply more duct tape over the blown section and keep flying!



Rick Schertle teaches middle school in San Jose and spreads the maker spirit through after-school classes. His wife and two young kids provide a constant flow of creative inspiration.

Damien Scogin

SKILL BUILDER

INTERMEDIATE

KINECT HACKING

Go from handwaving to coding with the Microsoft Kinect SDK.

By Joshua Blake

Kinect for Xbox 360 is an amazing little device stuffed with magical sensors. Its revolutionary power and affordability ($150 without the Xbox console) has sparked a wave of innovation in human-computer interfaces that engage the whole body. Now all kinds of games and gadgets can recognize your movements and gestures as commands to do all kinds of things, without you having to wear anything.

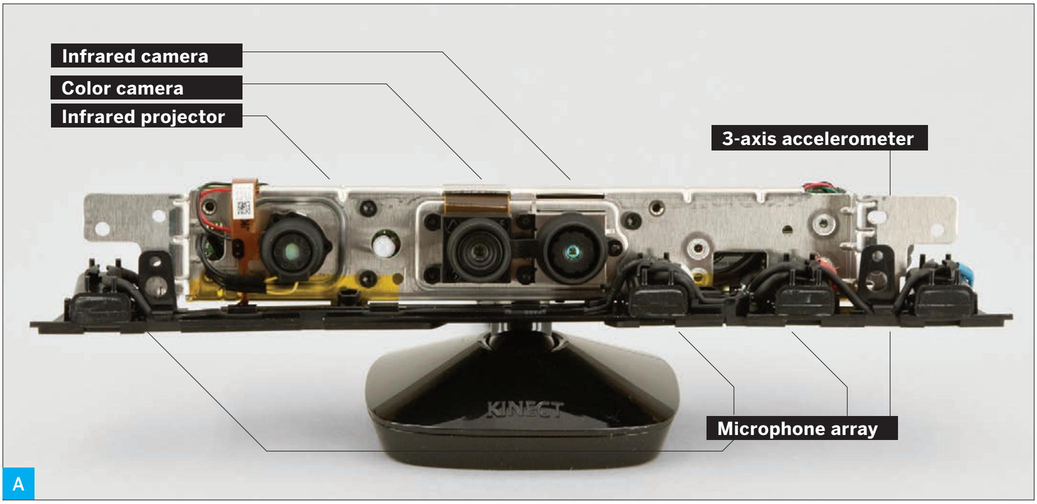
This article will explain what Kinect is, how it works, and how you can develop your own Kinect hacks. As a starter application, I'll explain the Kinect Weather Map, a live video application that changes your background to a different animated weather map whenever you walk across the frame and turn — just like a TV meteorologist, but without a green screen.

Joshua Blake (@joshblake) is an integrator (developer-UX designer hybrid) with extensive experience developing Natural User Interfaces (NUI) for Kinect, Microsoft Surface, and Windows 7 touch. He founded the OpenKinect community and is technical director of the InfoStrat Advanced Technology Group in Washington, D.C. nui.joshland.org

Portions of this article were adapted from the author's upcoming book, Natural User Interfaces in .NET.

Gregory Hayes

A POWERFUL SYSTEM Engineering intern Eric Chu shows off the author's Kinect Weather Map app in the MAKE Labs.



A

IN TERMS OF COMPONENTS (Figure A), Kinect integrates several sensors: a color (RGB) camera and an infrared (IR) camera, each capable of 640×480 pixel resolution at 30 frames per second (fps), a microphone array that isolates speech from background noise, and a 3-axis accelerometer, which is used to detect whether Kinect is level.

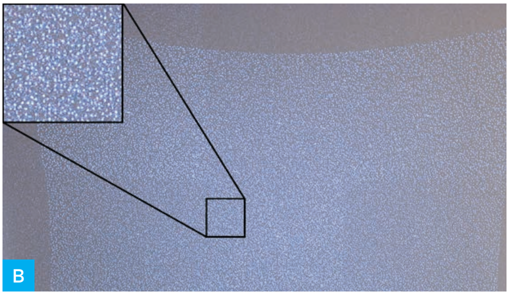
Along with the sensors are a motor that tilts Kinect up and down, and a laser IR projector that uses a diffraction grating to project a speckle pattern onto the world in front of it (Figure B). For power, Kinect requires 12V at 1.08A, which means you either plug it in with a wall wart or you can splice it to battery power, like an 8×AA battery pack.

THE Z-PLANE AND THE SKELETON

The IR projector and IR camera are where the magic begins. Here's a simplified explanation.

Every small grouping of dots in the projected IR laser speckle pattern is unique and recognizable to the IR image processor, even when deformed or displaced against the rest of the pattern. The IR projector is physically offset from the IR camera, about 5" left of it from the camera's POV, which lets Kinect triangulate a depth value by determining the shift of each dot group (Figure C).

Any point in the speckle pattern will shift rightward, as seen by the camera, as it


B

MATERIALS

Kinect for Xbox 360 retail box $150, includes the Kinect Sensor Power Supply that you'll need for plugging Kinect into your computer.

The "Xbox Console with Kinect" bundles do not include this power supply, but if you've already got a bundle, you can buy the power supply separately for $35.

TOOLS

Computer running Windows 7 with dual-core, 2.66GHz or faster processor, Windows 7-compatible graphics card that supports DirectX 9.0c, and 2GB RAM (4GB recommended).

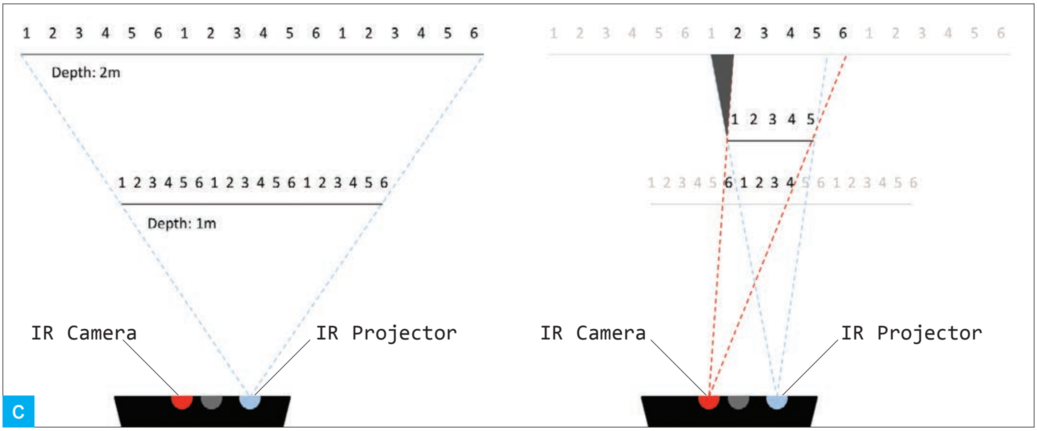
If you don't have Windows 7, you can still do everything described here with other Kinect drivers, but you'll need to translate the sample code into your own language and SDK of choice.

Compiler and IDE software Microsoft Visual Studio 2010 Express (free) or other 2010 edition

Kinect development software Kinect for Windows SDK from Microsoft (free), or *libfreenect* or *OpenNI* code libraries (free and open source).

If you want to do additional development with the SDK or try out the audio features of Kinect, see the Kinect SDK Readme for additional software to install.

futurepicture.com (B) ; Joshua Blake (C, D)



C

reflects off of a closer surface — like the way your car's headlights' reflections diverge as you approach a reflective surface.

Figure C shows an example of a horizontal slice representing dot brightness with numbers 1–6. In one part of its view field, the camera would see 6-1-2-3-4 reflected from 1 meter away, and 2-3-4-5-6 reflected from 2m. Also note the darkened triangle, which shows the area that the IR camera sees that is in the shadow of the object as illuminated by the projector. Kinect can't determine depth data for these parts of the scene without interpolating, giving possibly inaccurate values.

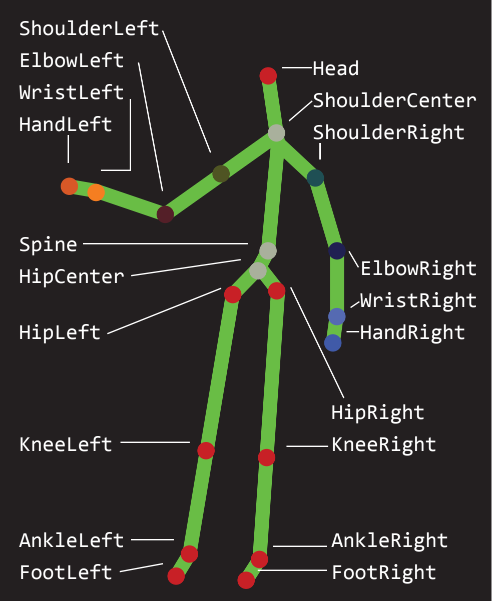
Kinect generates a depth image from each dot pattern offset, and transmits it via USB cable to the Xbox 360 or PC. Each pixel in the depth image represents a distance away from the camera plane in millimeters.

In addition, on the XBox 360 and PC, advanced software performs the sophisticated task of recognizing humans from the depth image and identifying (*x*, *y*, *z*) positions for up to 20 skeleton joints (Figure D). The depth image and joints are available to developers, along with the RGB image from the color camera. These images are mirrored, so when you face a Kinect and a display, your left hand shows up on the left side of the image.

KINECT HACKING SETUP

Commercial Kinect games are written using the Xbox Development Kit, which is only available to game studios with Xbox publishing

KINECT SDK SKELETON JOINT FIELDS



D

agreements. For the rest of us, the current best way to tap into Kinect is to write client applications for a Windows PC connected to Kinect via a USB cable.

To enable your PC to communicate with Kinect, you need to install a set of drivers and an SDK (software development kit) defining the structures you can call from your program to get the data. There are 3 options here: *libfreenect* and *OpenNI*, which were developed independently, and the Kinect for Windows SDK, which Microsoft officially released more

DRIVERS + SDK

libfreenect	OpenNI, NITE, & SensorKinect	Kinect for Windows SDK
Open source drivers developed by the OpenKinect community. First drivers published for Kinect.	Natural interaction framework and drivers published by PrimeSense, manufacturer of the chips inside Kinect.	Official Microsoft drivers for Kinect.
Pros: Many language wrappers and support for Windows, Linux, and Mac.	**Pros:** Support for Windows, Linux, and Mac. Open source except for skeleton tracking and gestures, which are provided by NITE, a closed source component.	**Pros:** Robust skeleton tracking.
Cons: Does not have skeleton tracking built in.	**Cons:** Multiple components to install from different sources. No microphone array or tilt motor support.	**Cons:** Requires Windows 7.

recently. Their pros and cons are summarized in the table above.

For this article, I'm using Kinect for Windows SDK, which requires a PC running Windows 7. (You can do everything described below with other Kinect drivers, but you'll need to translate the sample code into your own language and SDK of choice.) The Kinect SDK has a non-commercial use license during the beta, and a commercially licensed version is currently under development for release in early 2012.

If you already have *libfreenect* or *OpenNI* installed and you want to install the Kinect SDK, you must first plug in Kinect and uninstall the previous drivers. To do this, open Windows Device Manager, right-click the Kinect Camera, Audio, and Motor devices, and then check the "Delete the driver software" checkbox, and confirm by clicking OK. Then launch Add or Remove Programs, and uninstall any other driver installation packages listed that have Kinect in the name.

We'll write an application in 2 languages: XAML and C#. The visuals and controls are designed in XAML, a markup language for Windows interfaces that's based on the XML document language. To define how the interface elements behave, and to make them object-oriented, you associate them with a "code-behind" class written in C# (pronounced *see-sharp*), a language with a similar syntax to C++ that's used for writing Microsoft .NET programs.

To create this application, we'll use Microsoft Visual Studio 2010 Express, which is the free version of Microsoft Visual Studio 2010, a development environment that supports C#, XAML, Visual Basic .NET, and other languages. (If you have the full Visual Studio, you can also develop in that, of course.)

To get set up, download and install Microsoft Visual Studio 2010 Express from microsoft.com/express/downloads and the Kinect SDK Beta 2 from kinectforwindows.org. Download the 32-bit or 64-bit version of the SDK depending on your edition of Windows 7; if you're unsure, open the Start menu and right-click on Computer, click Properties, and check whether the System Type line says "64-bit." If you want to do voice-recognition applications, then there are a few additional components you also need to install, but for now this is all we need.

MAKE A KINECT WEATHER MAP

Use depth data (including the player index) to replace the video background behind a subject without using a green screen.

Here's an application that replaces the video background behind a subject with a weather map, the way TV meteorologists use green screens — except with Kinect, you don't need a green screen. You can easily adapt this technique to other backgrounds and uses.

E

Gregory Hayes

1. Get image and depth data from Kinect.

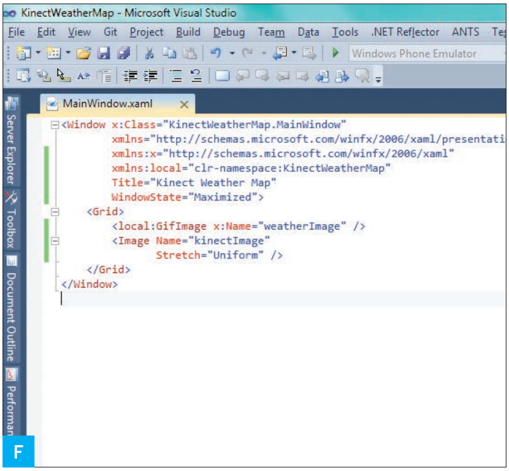
First we need to start getting data out of Kinect. Plug Kinect's USB plug into your computer and its power plug to an outlet (Figure E). If the SDK is installed properly, Kinect's LED indicator should blink, and a Windows pop-up may also indicate that the Kinect device is ready.

To verify communication to the PC, go to the Start menu under Microsoft Kinect 1.0 Beta2 SDK, and run the SkeletalViewer or ShapeGame samples. A zip file with source code for these samples can be found in the same location in the Start menu.

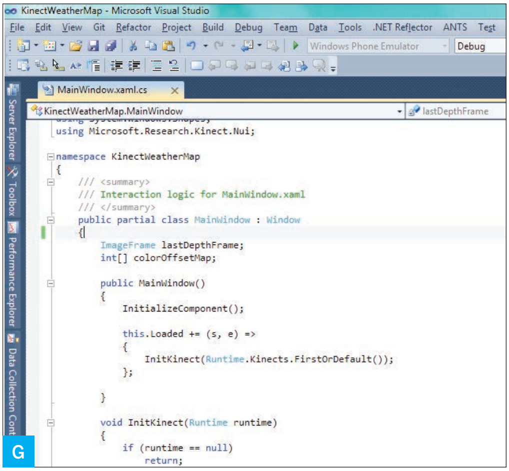
To create the project, launch your IDE (either Visual Studio 2010 Express or Visual Studio 2010) and select File → New → Project, then choose the WPF Application project template under Visual C# → Windows. (WPF, or Windows Presentation Foundation, is an interface framework that can encompass XAML elements with C# code-behind, as with our project.) Enter "KinectWeatherMap" for the project name, select a directory if you don't like the default one, then press OK. This creates a blank WPF application.

To tell your app to access the Kinect SDK, find the Solution Explorer (or select it from the View menu), right-click on References, and click Add Reference. Click the .NET tab in the popup, then find and select Microsoft. Research.Kinect and press OK. (To help find Microsoft.Research.Kinect, click the Component Name header to sort by name.) Now we're ready to write some code.

Double-click on *MainWindow.xaml*. This is auto-generated XAML code for the default first window that opens when you run the application. The file defines what visuals and controls are displayed in that window, and defines names for use in the code-behind class. The file already includes a `Window` tag and a `Grid` tag, and we'll add 2 `Image` tags to define the frames that will hold the Kinect camera image and the background weather image (Figure F, following page). To do this, replace the contents of *MainWindow.xaml* with:



F



G

```
<Window x:Class="KinectWeatherMap.➘
➥MainWindow"
   xmlns="http://schemas.microsoft.com/➘
➥winfx/2006/xaml/presentation"
   xmlns:x="http://schemas.microsoft.com/➘
➥winfx/2006/xaml"
   xmlns:local="clr-➘
➥namespace:KinectWeatherMap"
   Title="Kinect Weather Map"
   WindowState="Maximized">
  <Grid>
   <local:GifImage x:Name="weatherImage"/>
   <Image Name="kinectImage"
        Stretch="Uniform" />
  </Grid>
</Window>
```

The `GifImage` tag references our own control that supports animated GIFs like the ones we'll be pulling from the National Weather Service. You can find code for the `GifImage` class, along with all other code for this project, and updates for future releases of Kinect SDK, at makeprojects.com/v/29. This article steps through different versions of the code routines as we add functionality, so be sure to paste in the correct version for the step you're at.

Add the new `GifImage` class by right-clicking KinectWeatherMap in the Solution Explorer, then Add → Class. Name it *GifImage.cs* and then overwrite the file contents by pasting in the *GifImage.cs* code from the URL above.

To work with the C# class, the code-behind for the XAML, open the Solution Explorer panel in the IDE, then click the little triangle next to *MainWindow.xaml* and double-click on *MainWindow.xaml.cs*. Now we see the code-behind file and can write some code to talk to Kinect (Figure G). To tell the compiler where to find the class definitions used in the code, we declare:

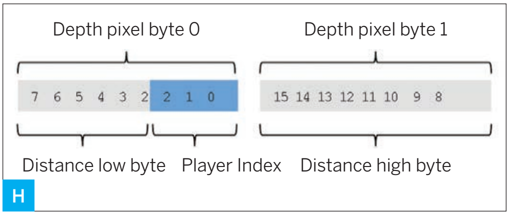
```
using Microsoft.Research.Kinect.Nui;
```

Below the `using` statements, inside the `MainWindow` class definition but before its constructor routine, add the following fields to store the most recent depth image and a color offset map that translates between pixel positions in the IR camera's depth image and color camera pixel positions:

```
ImageFrame lastDepthFrame;
int[] colorOffsetMap;
```

Inside the constructor, add the lines below, which call the `InitKinect` method (which we'll add next) to initialize the first Kinect plugged in. With no Kinect connected, the program will just silently do nothing.

```
this.Loaded += (s, e) =>
{
  InitKinect(Runtime.Kinects.➘
➥FirstOrDefault());
};
```



H


I

After the constructor in *MainWindow.xaml.cs* add the methods `InitKinect`, `runtime_DepthFrameReady`, `runtime_VideoFrameReady`, and `runtime_SkeletonFrameReady`, pasting the code in from makeprojects.com/v/29 . `InitKinect` configures Kinect to send us data and set up a `colorOffsetMap` array for us to use later, and the other 3 are event handlers that are called whenever Kinect sees new depth, RGB, or skeleton data.

Now try running the application by pressing the F5 key or selecting Debug → Start Debugging. You should see a window with the RGB video image streaming from Kinect. Hello, World! We're also saving the depth image in the `lastDepthFrame` field, for processing later.

2. Remove the background.

The depth image provides 2 values for each pixel: its distance from Kinect's camera plane (in meters), and the player index, indicating which player the pixel belongs to, if any. The player index ranges from 0 to 6, with 0 for no player (background or furniture), and 1–6 based on who enters the scene. In this application, each of the 76,800 pixels (320×240) in the depth image consists of 2 bytes that contain both the depth data and the player index (Figure H).

To remove the background, we're going to do some image processing using the player index. We'll create a new image to represent the foreground, initially set it to transparent, and then iterate over each depth image pixel. If the player index is not zero, we'll copy the corresponding RBG image pixel to our foreground image. Since we're using images from both the IR and color cameras, we also need to convert between the 2 slightly different sets of coordinates using the `colorOffsetMap` array that we set up in the constructor. All of this happens in the `runtime_VideoFrameReady` method that we created earlier. Copy the "Remove the Background" version of the code from makeprojects.com/v/29, and paste it into the project code.

We're only using the player index, but if you also wanted to retrieve the depth data from the image, you could add the following line inside the method's inner `for` loop, after defining the `depthIndex` variable:

```
short depth = (short)
 ((depthBytes[depthIndex] >> 3) |
   (depthBytes[depthIndex + 1] << 5));
```

Now compile and run the application. You should see a blank white background on your computer, until you or someone else moves into Kinect's field of view, at least from the waist up. When you do, the player index will become non-zero for pixels where Kinect is tracking your body, the code will copy over those color pixels, and you'll see an image with only people and no background (Figure I) — like a green screen without a green screen!

You may notice that the "cutout" doesn't always match the RGB image, especially if you're moving quickly. This glitch is partly noise, partly because the RGB and depth frames may not be delivered at exactly the same rate, and partly because our code is simplified for learning, rather than optimized for speed. There are several techniques an

Joshua Blake

intermediate developer could use to speed up the code and to sync the RGB and depth frames better, based on timestamp.

3. Track the skeleton and add the maps.

Finally, we want to add the weather maps in the background and be able to switch them using a simple gesture. To recognize the gesture, we'll use Kinect's skeleton tracking data.

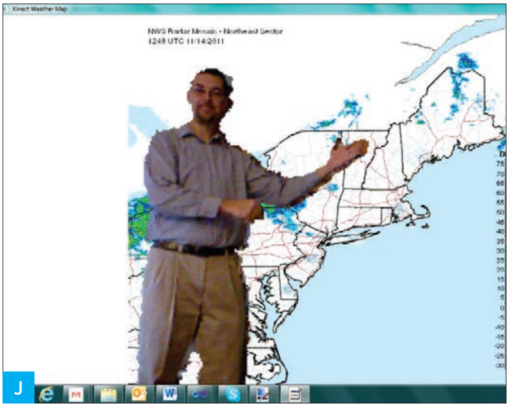
What kind of gesture? Broadcast meteorologists often change the weather map as they walk across the screen and pivot to face the opposite direction. To detect this gesture, we need to check 2 conditions: which side of the image the `ShoulderCenter` joint is on, and whether the left shoulder or right shoulder is closer to the camera. If both of these conditions change from their previous state, we know the user has performed the walk-and-turn gesture and we can cycle the background image. We check for turning so that the background doesn't cycle when the user is just reaching for the far side of the map.

To add this feature, we first need to add a few fields at the top of the `MainWindow` class:

```
int currentBackground = -1;
List<string> bgImages = new List<string>();
bool isPoseLeft = false;
bool isPoseRight = false;
```

To retrieve the map images, add the following inside the `MainWindow` constructor after the call to `InitializeComponent()`. You can substitute the URLs for other animated GIF maps provided by the National Weather Service:

```
bgImages.Add("http://radar.weather.gov/⤵
➥ridge/Conus/Loop/NatLoop_Small.gif");
bgImages.Add("http://radar.weather.gov/⤵
➥ridge/Conus/Loop/southeast_loop.gif");
bgImages.Add("http://radar.weather.gov/⤵
➥ridge/Conus/Loop/northeast_loop.gif");
bgImages.Add("http://radar.weather.gov/⤵
➥ridge/Conus/Loop/pacnorthwest_loop.gif");
bgImages.Add("http://radar.weather.gov/⤵
➥ridge/Conus/Loop/pacsouthwest_loop.gif");
CycleBackground();
```



Now update the `runtime_SkeletonFrameReady` method to the code version under "Track the Skeleton" at makeprojects.com/v/29, and also add the new `CycleBackground()` method, which cycles through the background images with each body-turn gesture. The code will find the skeleton closest to the Kinect and use shoulder positions to determine if the skeleton is facing right or left, and if the pose changes it will call `CycleBackground` to put up a new animated background image, which is downloaded automatically (Figure J).

Now stand up, and with your best voice, describe and gesticulate over the weather map background. To change images, walk to the other side of the image while turning your shoulders toward the center.

Congratulations, you've just made a Kinect hack! Now go show it off to your friends and see what else you can come up with.

+ For project code, video of the Kinect Weather Map hack in action, and other resources, visit makeprojects.com/v/29.

Joshua Blake

MORE FUN KINECT HACKS

Here are some other great Kinect hacks; find the links at makeprojects.com/v/29.

SWORDFIGHTING The **Kinect JediBot** is a robotic arm that holds a toy lightsaber and engages in swordfights against human opponents.

OBJECT SCANNING Kinect can scan objects for conversion into 3D images used in design, animation, and 3D printing. The **Kinect Turntable 3D Scanner** scans small objects on a small rotating stage, while the **Kinect 3D Object and People Scan** builds up 3D images of larger objects with Kinect hardware in a handheld wand.

HELICOPTERS A YouTube sensation, **UC Berkeley's Quadrotor project** puts Kinect on an Ascending Technologies Pelican R/C helicopter, enabling it to autonomously navigate indoors, follow coded signs, and avoid being swatted. **Jonathan Oxer** uses an offboard Kinect to control an ARDrone Parrot copter with simple, dog-trainer hand gestures.

ASSISTIVE TECH (top) The NAVI project (**Navigational Aids for the Visually Impaired**) pairs a Kinect mounted atop a helmet with headphones and a vibrotactile waistband to enable blind people to find their way around and avoid obstacles, cued by audio messages ("Door ahead in 3," "2," "1," "Pull the door") and vibration at different points around the waistband.

"MINORITY REPORT" INTERFACES (bottom) **Minority Report Software for Kinect** enables the interface style seen in the movie *Minority Report*, in which people navigate wall-sized representations of large data sets with hand and arm movements. The **Kiwibank Interactive Wall** enables users in front of a projection wall to fly through a simulated space by steering their arms like wings.

TABLETOP SIMULATIONS The **Kinect Augmented Urban Model** allows users to build up an urban landscape on a full-screen tabletop and simulate the buildings' shadow patterns at different times throughout the day.

MOTORIZED LOUNGE CHAIRS **Jellybean, the Kinect Drivable Lounge Chair**, lets the user drive around with simple hand gestures while seated comfortably.

HCI Group University of Konstanz (top), Lumen Digital Ltd. (bottom)

$4 Hot Air Balloon

Up, up, and away, with Scotch tape and a painter's drop cloth.

By Jesse Brumberger

ON A JUNE AFTERNOON IN 1978, WHILE most normal kids were focused on sports or getting Dad's car keys, I was busy readying another one of my quixotic contraptions, made out of junk-at-hand, for its maiden voyage. Assisted by a good friend who also enjoyed such nerdy pursuits, I stoked a fire inside an improvised burner and slowly, carefully inflated the large, fluttering balloon I had fashioned out of plastic drop cloths, Scotch tape, and coat hangers.

The sides of the plastic envelope became warm to the touch, and I could feel a slight upward tug on the hoop that framed the inlet at the base of the balloon. My friend and I took turns steadying the giant transparent chrysalis over the chimney and gleefully fueling the fire with old exams and papers from the just-completed school term. Another minute passed; the balloon felt very warm and I could feel its positive buoyancy. I wasn't sure how hot the top might be getting and didn't want to press my luck. I released the hoop.

The balloon lifted upward perhaps 10 feet clear of the chimney. It seemed to hesitate there, as though comprehending its new freedom, and then accelerated skyward with a swirling whoosh. To my total surprise, it kept climbing past treetop level, 100 feet, then 200 feet, and began to drift as it climbed. First it cleared the field, then the neighborhood, and then went out of sight over the hills.

Our elation was only slightly dampened by my father's reprimand for our irresponsibility

Zachary Brumberger

and my mother's aggravation over the disappearance of yet more household supplies — aka "engineering materials."

We went on to fly more balloons (tethered), one even carrying a half-pound camera aloft. Years later, I bought and flew a ready-made model hot air balloon with my son. While more colorful to look at, it didn't fly nearly as well as our homemade versions had. For all you readers who enjoy that special kick that comes from seeing an unusual homemade rig actually work, here's some fun that can be had on a kite-string budget.

Specifications

My original balloons were fashioned from two 9'×12', 0.7mil plastic drop cloths, seamed together into a cylinder along their 12' sides. The finished envelope enclosed a volume of roughly 230 cubic feet (6.5 cubic meters), weighed 15oz (425g), and would lift again as much in payload when thoroughly heated. Unladen, these balloons had lots of extra lift for rapid climb and a long flight before cooling enough to descend.

The single-drop-cloth balloon presented here encloses about 75ft^3 (2.1m^3), weighs about 8oz (227g), and will provide another 4oz (113g) of extra lift when heated to the plastic's safe capacity. These smaller balloons provide shorter flights but are much easier to handle.

1. Make the balloon envelope.

Lay out the drop cloth on a smooth, clean floor. Place a strip of cardboard or wax paper (a separator) on top of the drop cloth, running down its centerline, parallel to the 9' sides.

Fold the 9' edges over so they meet on top of the center separator (Figure A). You may find it helpful to first place a strip of tape, sticky side up, in the center, then draw the 9' edges to meet at the tape so the edges are abutting and parallel.

Tape the edges together to form a 9'-long cylinder, trying to overlap the tape evenly onto both sides of the seam (Figure B). Goofed spots can be double-taped later. The separator may now be removed.

MATERIALS

FOR THE BALLOON

Painter's drop cloth, 0.7mil plastic, 9'×12' (3m×4m)
Wicker or small-diameter hard plastic pneumatic tubing, 5' (1.5m) or similar
Transparent tape, ¾" (19mm), 1 roll e.g. Scotch tape
Duct tape a few pieces
Twine, lightweight cotton, 300' (100m) or similar for the tether line, not susceptible to melting
Cardboard or wax paper to act as a separator in Step 1

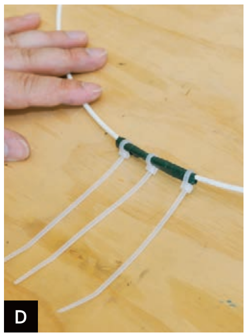
FOR THE BURNER

Stovepipe, aluminum or black steel, 6" (150mm) diameter, a few feet
Heat register box, aluminum or heating duct elbow, or scrap sheet metal, for the firebox
Screen, metal, about 6"×6" or slightly bigger


A


B


C


D

2. Close the top.

At one end, gather in the plastic as evenly as possible from points every ⅛ of the way around. Twist tightly together for a few inches and secure soundly with tape or a couple of twist-ties or zip ties (Figure C).

3. Make the inlet.

Form the tubing into a hoop about 1½–2' in diameter and splice it with duct tape. For springy materials, reinforce the tape with zip

Gregory Hayes

E

F

ties (Figure D). Don't use wire for the hoop (in case the balloon runs afoul of power lines), or wooden doweling (it snaps and splinters).

Gather the other end of the cylinder as evenly as possible, wrap it around the hoop from the outside inward, and tape it every few inches to form a hem a few inches up inside the bottom of the balloon (Figure E).

4. Check for holes.

Inflate the completed balloon by holding the open end in front of a small fan (Figure F). Identify any holes and tape them. Tie the tether line to the hoop and secure it with tape, or use kite line attachment links if you wish.

Jesse Brumberger is a mechanical engineer of 25 years experience and a graduate of Syracuse University. He enjoys building and making all sorts of things, from model aircraft to precision-machined miniature running engines.

HEAT SOURCES

An **electric heating gun/paint stripper** has enough power to heat the balloon for short test hops in the backyard, and it helps inflate the envelope while heating. Other heat sources, such as **multiple cans of Sterno** grouped beneath a short metal chimney, may be experimented with.

But the classic **wastepaper/stovepipe burner** provides maximal heating for this balloon. You can make the burner from a few feet of 6" stovepipe and a firebox made from an aluminum register box, a ductwork elbow, or scrap sheet metal. Black steel or aluminum is best, as galvanized steel ducting produces unhealthy zinc-oxide dust when exposed to flame. The burner shown here has a firebox fashioned from scrap aluminum flashing and a large cookie tin, riveted together in about 10 minutes.

Fit the firebox to the bottom of the pipe and place a piece of screen over the top of the chimney to prevent burning bits of paper from escaping.

Unless you're flying on a steel wire in the middle of nowhere, it should not need saying that a heat source should never be sent aloft on a balloon.

Zachary Brumberger (bottom sidebar, opposite)

Flying Your Balloon

HAVE FUN AND HAPPY FLOATING!

1. CONDITIONS
Absolutely calm air is required for the balloon to be manageable while heating. Dawn and dusk often provide these conditions, as do winter days of high pressure when it's clear and very cold. You also get more lift when it's cold outside, because buoyancy is a function of the difference in air density outside and inside the balloon.

2. FIND A LOCATION
Identify a flying field where you can safely and legally make a fire. Bored park police may create some real drama if they find you building a fire outside of a barbecue grill. Keep a fire extinguisher or at least a bucket of water handy along with a pair of leather gloves. As with kite flying, make sure no overhead power lines are anywhere nearby. Be sure to locate your burner on sand or stone, off the grass, away from flammable scrub, and then stabilize it with bricks or a metal stake as required.

3. TETHER
Do not attempt to launch a balloon without a tether. Even when it's dead calm on the ground, there are always winds aloft, and a well-heated free balloon can be lost before cooling and descending somewhere. As my father angrily pointed out to his teenage kid, the huge plastic bag could come down in traffic, on electrical equipment, over a rooftop exhaust pipe, or on top of young children. Even if it just festoons somebody's treetops, it's not a good situation.

4. PREPARE THE FIRE
Pay out some tether line along the ground before launch. Next, prepare a supply of newspaper wads several feet away from the burner, then start a fire in the firebox.

5. INFLATE
Now here's the tricky part. Partially inflate the balloon by wafting the hoop through the air, and then quickly stand it as upright as possible over the heater while an assistant helps. It may be helpful to use a pole to hold up the topknot until the balloon begins to fill out. It's critical to keep the plastic from draping too close or touching the chimney, as it will instantly melt through. When using the heat gun, keep it moving and keep its end far from the plastic. A few small holes near the bottom of the balloon are inevitable and inconsequential.

6. LAUNCH & ASCEND
After several seconds the balloon will begin to fill and loft itself. Keep the hoop centered over the heat source as you continue heating. It will become buoyant quickly. Place a hand against the side of the envelope as high up as you can reach. When the side feels very warm about halfway up, perhaps 150°F (65°C), the top will be approaching its limit around 200°F. Check that the tether is secure and release the hoop, gently escorting it straight up from the chimney. Pay out the tether line and watch your balloon ascend.

⚠ **CAUTION:** The combustion gases flowing up into the center of the balloon are much hotter than the airflow near the sides and can sear faces or lungs if you get into their path. Be careful not to burn through the tether line!

7. EXPERIMENT
You can experiment with lofting small payloads such as a mini digital camera, an altimeter, etc. Try making balloons of different sizes and shapes. Maybe find some colored plastic. Or how about a hot-air dirigible with a small electric motor and lithium polymer battery?

Hovercraft Shop Vac

Mod your vacuum to float obediently behind you on a cushion of air.

By Bill Wells

I HAVE OWNED SEVERAL SHOP VACUUM cleaners, but regardless of the make, I never liked the way the casters worked. They never rolled where I wanted them to.

When I recently had to replace a worn-out shop vacuum, I looked for a way to improve the mobility of the new machine. That's when I realized that the vacuum's discharge air might be a way to do this.

I decided to make the vacuum self-levitating, to turn it into a hovercraft. Then it would just obediently float along the floor behind me. Here's how I did it.

1. Mount the vacuum to the hovercraft deck.

First I bought a ¾"-thick × 24"-diameter MDF disk at a local home center, and attached my new vacuum, without wheels, to the center of the disk with a few ½" wood screws.

The canister is made of plastic, and the screws can be driven right through the bottom into the MDF. Don't worry about the holes in the canister; they're small and could easily be patched later.

2. Install the hover hose.

I used a hole saw to cut a 2"-diameter hole in the disk, and used more wood screws to attach a 2½" universal dust port fitting for connecting a hose.

I had kept the hose from my old vacuum, so I used it to connect the air discharge on the new vacuum to the new fitting on

Bill Wells

MATERIALS AND TOOLS

Shop vacuum Any type that has a separate exhaust port will probably work. I used a 12gal Shop-Vac Pro, a standard size sold at hardware stores. It's got 5HP peak power.
Round MDF disk, 24"-diameter × ¾"-thick sold in home centers in the pre-cut plywood section
Shop vacuum hose, 2½" diameter In addition to the hose you use for vacuuming, you need this spare hose to connect the vac's air discharge to the hovercraft deck. This is the standard hose that comes with the larger vacuums, available in home centers or online. The nozzle diameter is actually 2¼".
Universal dust port I used a 2½" port from rockler.com (item #92031), but your hose size may vary.
Foam strip, minimum ½" thick × 1½" wide, about 80" total length for the hovercraft skirting. This may have to be scrounged; I cut mine from an old exercise mat.
Nails, 1", about 3 dozen
Wood screws, ½"
Hole saw, 2" diameter or jigsaw
Electric drill
Hammer
Heavy scissors or utility knife to cut the foam strip

the deck (Figure A). It's a standard 8'-long, 2½"-diameter Shop-Vac hose, which I wound around the canister so that I wouldn't have to cut the hose. The hose only needs to be about 2' long; if you cut it down, be sure to use the threaded end to connect to the vacuum's discharge port.

3. Make the hover skirt.

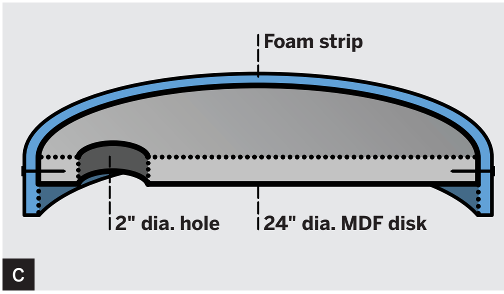
Making and attaching the skirt is the only challenging part. The skirt needs to be strong enough to support the vacuum when it's not in operation, but flexible enough to form a seal to hold in the air when hovering.

After some experimenting, I cut a 1½" wide strip from an old ½"-thick exercise mat, but similar material will do. I attached the skirt using 1" roofing nails spaced about 2" apart (Figure B). Other small nails will work fine also, but don't use anything under 1" length. If you cut the skirting material carefully, it will be straight enough to create a good air cushion for the vac to float on.

A schematic cross section view of the deck and foam skirt is shown in Figure C.

A

B



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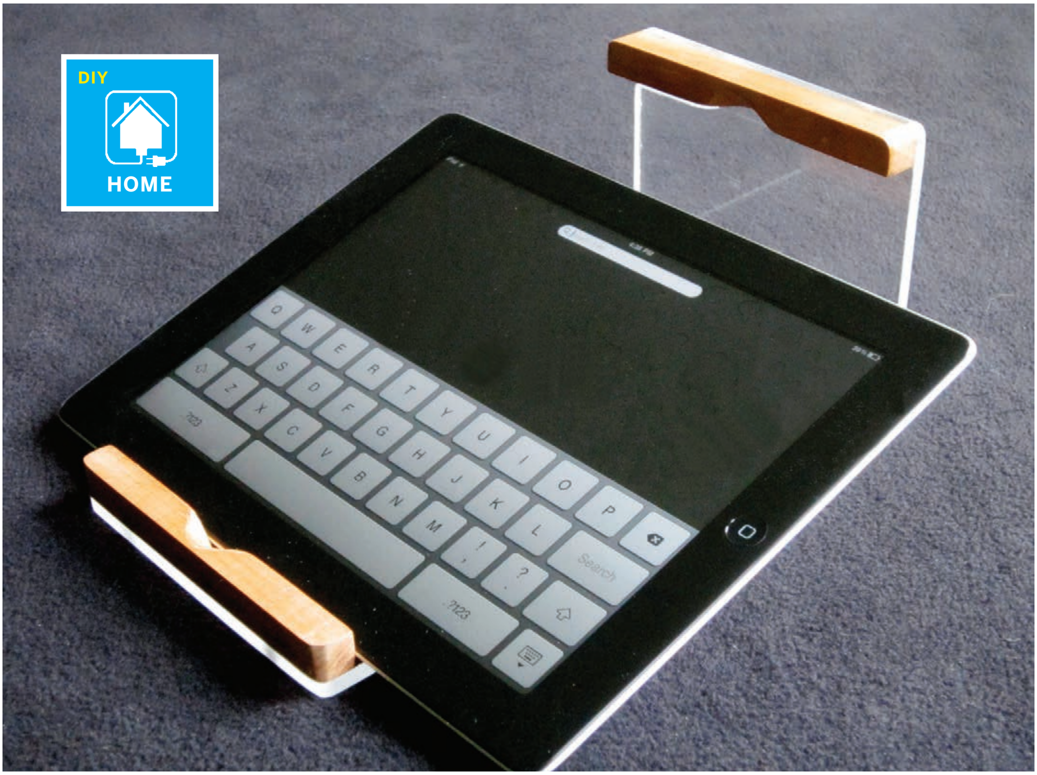
I was initially concerned that performance of the vacuum might be affected by partially restricting the air discharge. This proved not to be an issue, as the suction and volume of air through the vacuum are the same now as before I turned it into a hovercraft.

As I had hoped, the vacuum now effortlessly floats along the garage floor behind me on its own cushion of air. As you might expect, it works best on uncarpeted floors. Come along, my little shop vac hovercraft.

Bill Wells is a retired engineer living in Olympia, Wash. He now makes woodworking devices in his garage shop, many of which have appeared in woodworking magazines, and has had a patent issued on one of his designs.

Damien Scogin (C)



iStand

Build a sturdy, multi-position iPad stand for cheap.

By Larry Cotton

THE iPAD, WONDERFUL AS IT IS, OFTEN needs a stand to hold it. Sure, there are tons available, but they can be flimsy and/or expensive. Here's one that's cheap, sturdy, and easy to build. It'll hold either the original iPad or the iPad 2 in many useful positions.

It's made from ¼"-thick clear or smoked acrylic, a few scraps of nice wood, a small piece of adhesive foam, and 6 screws.

MATERIALS AND TOOLS

Acrylic sheet, clear or smoked, 5"×13⅝"×¼" aka plexiglass
Wood strips and block: 5"×½"×½" (2), 5"×2"×¾" (1)
Self-adhesive foam sheet, 5"×¾"×0.083" or 1⁄16"
Flat-head wood screws, #8×¾" (6)
Saw for wood and acrylic, ideally a band saw or jigsaw.
Drill, ⅛" bit, countersink, high-speed rotary tool, sandpaper, aluminum foil, felt pen, wood scrap 4"×4"×6", electric stove, disk sander (optional)

Make the Stand

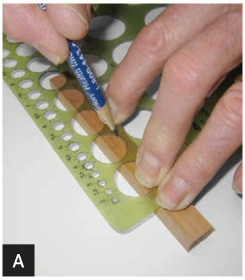
1. Cut 2 wood strips 5"×½"×½". In the center of each, rough in a Home button access groove using a band saw or jigsaw (Figures A–C).

Finish with a Dremel and sandpaper (Figures D–F). Groove shape isn't critical, and may need to be tweaked later.

2. Leave the protective paper on the acrylic for now. Cut the acrylic to size and sand its edges (Figure G). On one end only, drill and countersink 2 holes (Figure I and J).

3. For the original iPad, cut a slot on the same end to expose its down-firing speaker (Figures G and H). Skip this step for iPad 2.

Larry Cotton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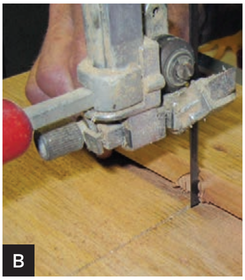
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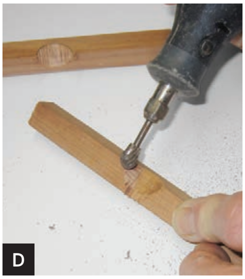
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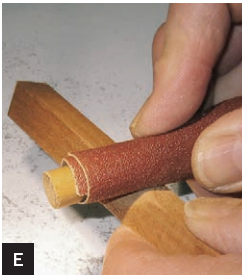
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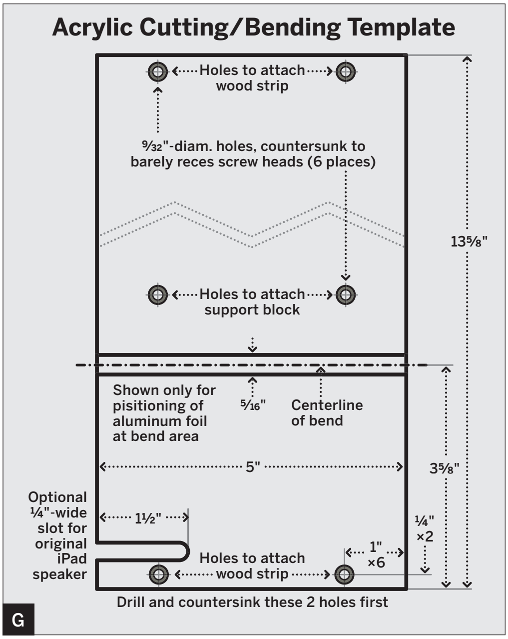

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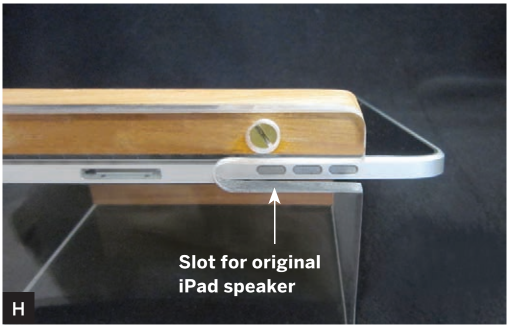

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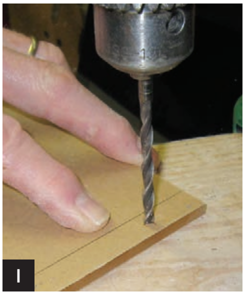
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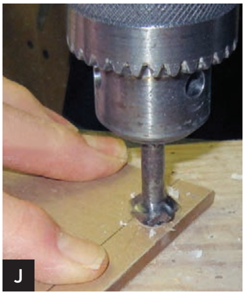

J

Damien Scogin (G)

4. Cut a 6" length of scrap 4×4 wood to use as a 90° bending fixture for the acrylic.

5. On the same end of the acrylic as the screw holes, pull back and remove about 4" of the protective paper on both sides.

6. Note which side of the acrylic the countersinks are on. Wrap both ends of the acrylic with aluminum foil. On the foil, mark a dot with a felt-tip pen on the countersinks' side. Leave exposed a 5⁄16"-wide bend area, as shown on the template and Figure K (following page). The foil will shield heat from everywhere except that area. To ensure an accurate, neat bend, use the straight factory edges of the foil at the gap, ensuring that they're perpendicular to the sides and parallel.

7. Heat the bend area over a red-hot electric stove burner. Hold the acrylic 1–2" above the burner and flip it over frequently to ensure that both sides are heated evenly. Keep the piece moving, and don't allow the aluminum foil to slip (Figure L).

8. After about 30 seconds, push on the short end of the acrylic to see if it begins to yield. You want it to bend easily, but don't heat it so much that bubbles begin to form.

9. When the bend area is pliable, remove from heat, then quickly (holding onto the cool foil-wrapped ends) bend the acrylic over the 4×4 wood — with the felt-tip dot on the outside — and let it cool. Hold it under cold running water to speed the process (Figures M and N).

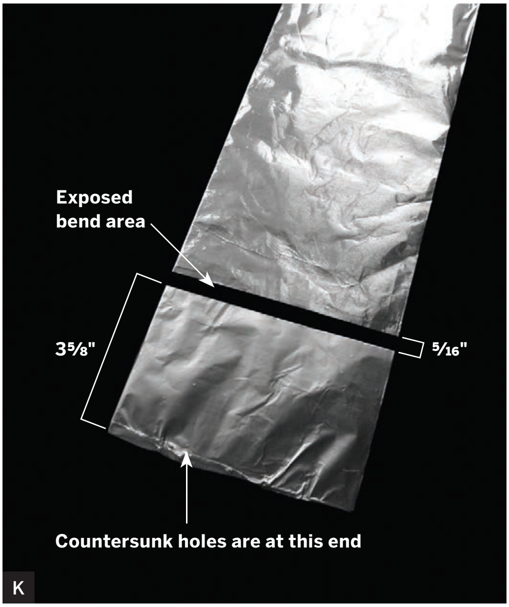
10. Noting the position of the Home button access groove, place one wood strip flush with the short end of the acrylic and over the 2 screw holes. Trace the holes onto the wood (Figure O), then drill almost through with a ⅛" drill bit. Attach with 2 screws.

The screws could raise a bulge in the wood if the countersinks are too deep. If so, you can either drill all the way through the wood strips and sand the ends of the screws flush, or sand a little off the ends before attaching the wood pieces to the acrylic. Don't use shorter screws.

11. This step helps ensure the stand will accommodate both iPads. Set the stand on its short leg, and put your iPad in its portrait (steep-angle) position with its bottom edge trapped by the wood strip. Hold the other wood strip on top of the iPad, noting the relative position of the groove, and mark where it will be mounted (Figure P).

12. Attach the wood strip to the acrylic as you did the first one and trim the excess acrylic flush. Now gently round the 4 corners of your iStand; a bench disk sander works well.

Your iPad is now usable in portrait orientation, at either a steep or shallow angle.



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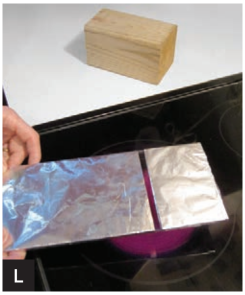
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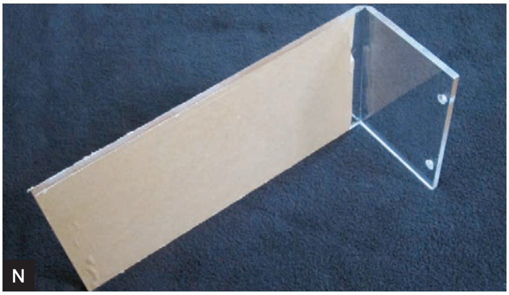
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O

Add a Wooden Support Block

To use your iPad in landscape and charging positions, add a wooden support block.

1. Cut (preferably on a band saw) ¾" wood stock to 5"×2", then cut an approximately 20° angle (Figure Q) on one long edge.

2. Put your iPad in the stand in steep-angle portrait position, either slid in from the side or snapped behind the top wood strip. The acrylic will yield somewhat.

3. Slide the support block into position with the angled surface against the back of the iPad and the other side against the back of the stand. Your goal is to center the support just above the center of the Apple logo. Trim it to fit.

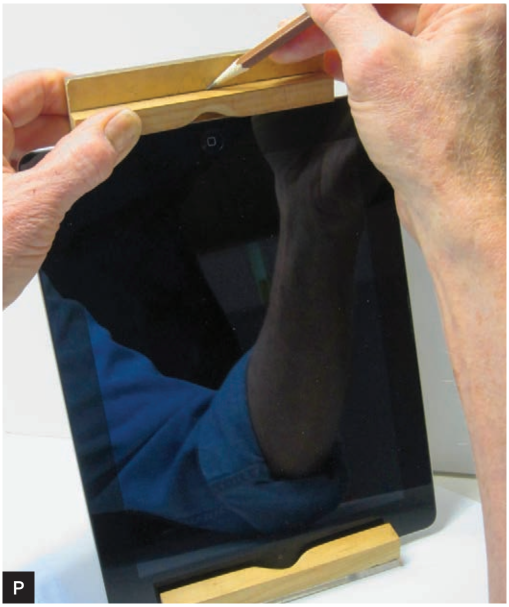
4. Attach a ¾"×5" piece of thin pressure-sensitive adhesive foam to the angled surface.

5. Reposition the support block, and where its top edge meets the acrylic, mark a straight line on the acrylic, perpendicular to the edges (Figure R). Remove the block.

6. At ⅜" below that line, mark, drill, and countersink 2 mounting holes in the acrylic.

7. Once again, slide the support into position, trace the acrylic's mounting holes onto it, and drill two ⅛" holes, about ½" deep.

8. Remove the wood strips and the acrylic's protective paper. Finish the 3 wood parts with oil, wax, or polyurethane varnish and reassemble the stand.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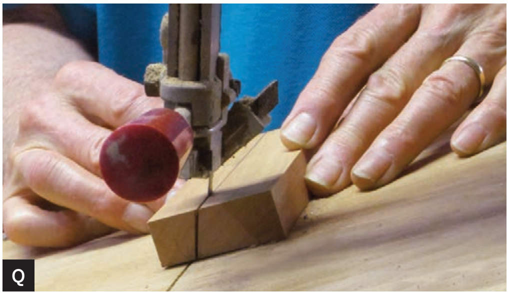
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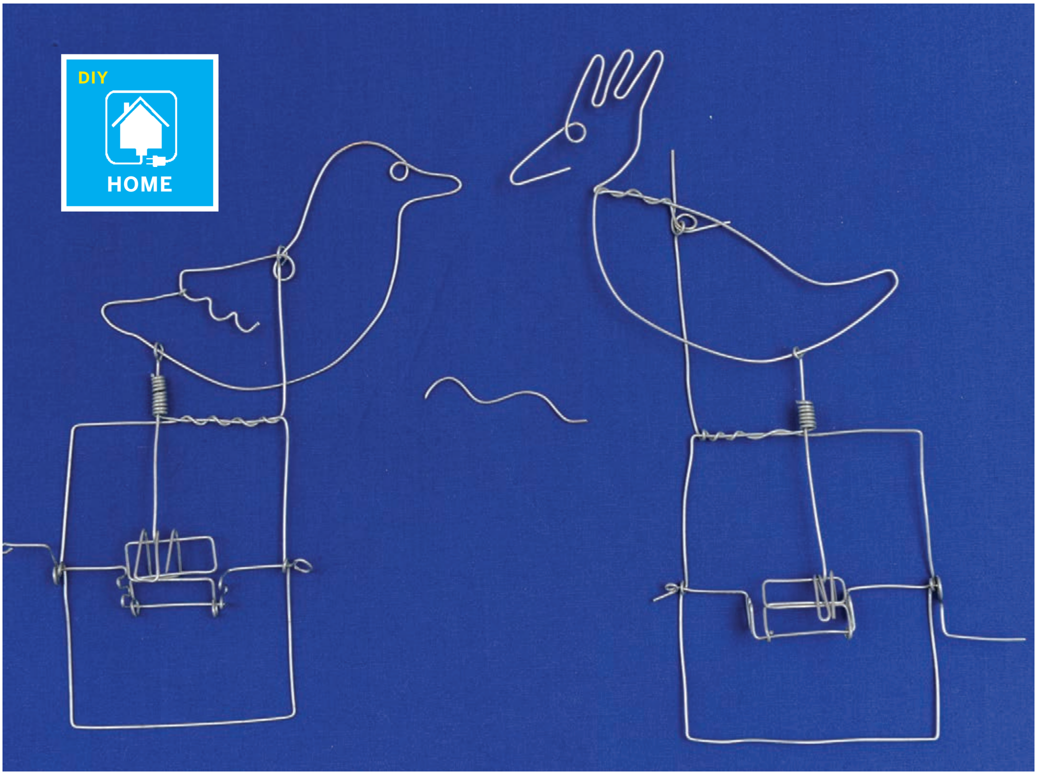
R

Larry Cotton is a semi-retired power-tool designer and part-time community college math instructor. He loves music and musical instruments, computers, birds, electronics, furniture design, and his wife, not necessarily in that order.



Bent-Wire Crank Toy

Learn these tricks and turn plain wire into a head-bobbing toy.

By Lea E. Albaugh and Matt Mets

MAKING THINGS WITH WIRE LOOKS simple, but it can be challenging. Pick up a few wire-bending tricks, though, and you can sketch in 3 dimensions and make anything from a tiny, delicate figurine to a large, mechanical sculpture with moving parts.

Like sketching with a pen on paper, there's no right way to do it, but a few techniques can help you get started. We'll show you how to make a functional crank toy using a few basic tools and ordinary fence wire. Along the way, you'll learn some important bends and structures you can use in your own creations (Figure A).

Our crank toy is made up of 5 pieces: frame, crankshaft, piston, connecting rod, and art. Each part is made separately using individual pieces of wire, but you need to construct them in the right order so they'll fit together correctly. To make it easier, we've made a template to guide you. Download it at makeprojects.com/v/29, and use the template and the photo above for reference.

1. Fabricate the frame.

Measure out about 24" of wire. Start by making the *cylindrical coil* at the top of the frame. Wrap your wire around a prong of your pliers (round-nose work best), and bend into a coil, slipping the coil off as it grows (Figure B).

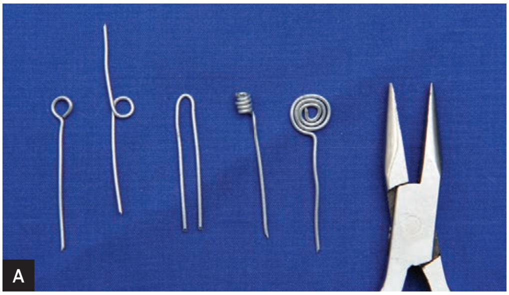
Working your way around the template, next grip the wire in the pliers' jaws and bend it to make a right angle.

To make a *continuing loop*, grab the wire at

Matt Mets, featuring the hands of Lea Albaugh

MATERIALS AND TOOLS

Wire, 20 AWG, bare We got a spool of fence wire that will last for a long time for $3.
Pliers, needlenose A second pair is optional but handy.
Wire snips
Template Download it from makeprojects.com/v/29.
Pliers, round nose (optional)
Ruler (optional)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the intended location of the loop with the tip of the pliers and wrap (Figure C).

Follow that with 2 more right angles and a second continuing loop. The 2 continuing loops on opposite sides of the frame should be level with one another.

Wrap the trailing edge of wire around the top of the frame to the far corner and leave the end long for now (Figure D).

2. Create the crankshaft.

Measure out about 8" of wire. To make a *zig-zag*, make a series of 180° bends around the tips of the pliers, then tighten them by squashing them with pliers (Figure E).

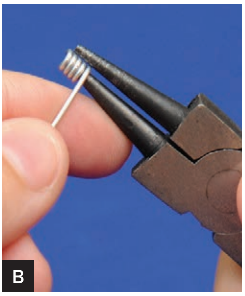
To make a *flat coil*, twist a loop perpendicular to the main shaft, then continue to spiral the wire around the loop, keeping it in plane by gripping it with the pliers (Figure F).

After completing it as shown on the template, make right-angle bends (indicated with stars), perpendicular to the plane of zig-zags, to finish the crankshaft (Figure G).

Open the continuing loop on the side of the frame away from the trailing edge by twisting it sideways. Slide the handle end of the crankshaft into the open loop. Trim the long end of the shaft to slip it through the opposite loop (Figure H, following page).

Finally, make a *terminal loop* to secure the crankshaft in the frame. Make a right angle bend in the crankshaft just on the outside of the frame, and trim the trailing end to about ½". Turn it so the bent end is facing you. Grip the end in the tip of the pliers, and curl the end back in one smooth motion. Neaten the loop with the tips of the pliers (Figure I).

You've finished the crank (Figure J).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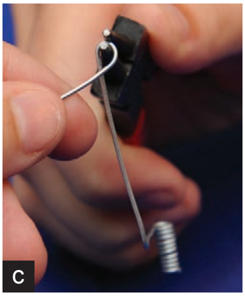
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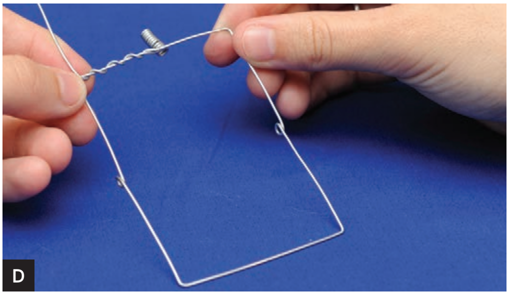
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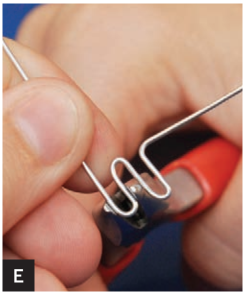
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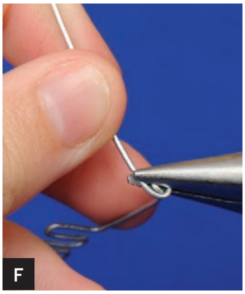
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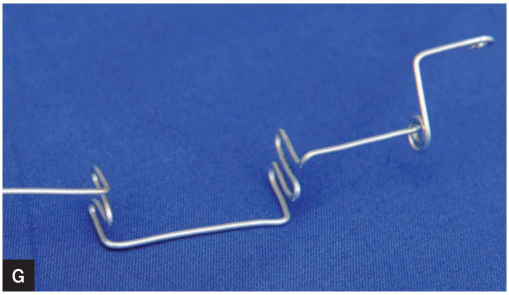
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3. Prepare the piston.

Measure 6" of wire, and follow the template to create the basic shape (Figure K). Grip both long edges of the rectangle in the pliers, then bend the rectangle over to make a V in profile. Twist the loop so that it lies parallel to the V edges (Figure L). Leave the long end trailing.

4. Construct the connecting rod.

Measure 5" of wire and follow the template for the first half of the connecting rod. Slide the piston onto the top edge of the rod, with the V edges straddling the sides (Figure M), before completing the template shape (Figure N).

Twist open the loops at the base of the connecting rod.

5. Mount the mechanism.

Thread the trailing end of the piston through the cylindrical coil on the frame, hook the base of the connecting rod onto the crankshaft (Figure O), and close the loops by twisting them back into position.

6. Build the bird.

Follow the template to bend your choice of bird. Turn a loop at the top of the piston, and another at the top of the frame. Twist open the loops, attach the bird, and close them.

Further Inspiration

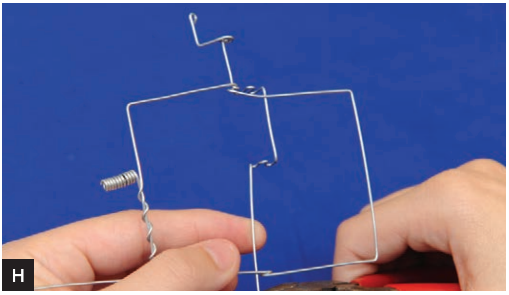
These days people make automata, or actuated mechanical sculptures, out of materials like metal, wood, and paper. Wire's great too.

Alexander Calder, famous for his mobiles, also experimented with directed motion in expressive, evocative bent-wire crank toys.

Arthur Ganson's soldered wire automata (youtube.com/user/dreamingmachines) are lovely and futile. His work is fascinating.

Lea E. Albaugh is a recursive acronym. She makes things to hold, wear, and inhabit, and writes interactive fiction. lea@instamatique.com

Matt Mets is a classically trained electrical engineer, and enjoys inventing instruments, hacking on open hardware projects, and traveling the country to visit hackerspaces. He likes to make his own food and derives much of his inspiration from puns. matt.mets@cibomahto.com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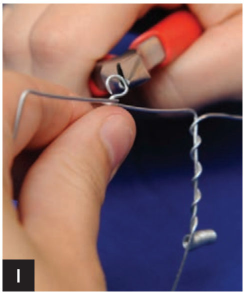
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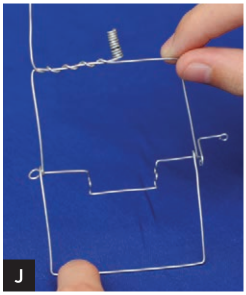
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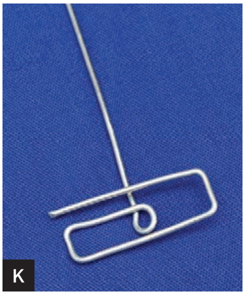
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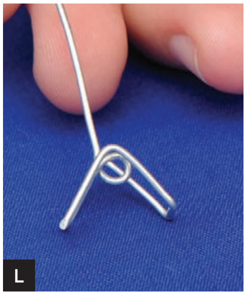
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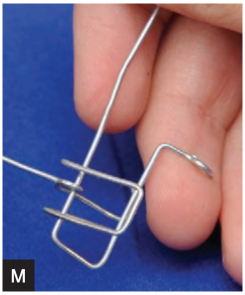
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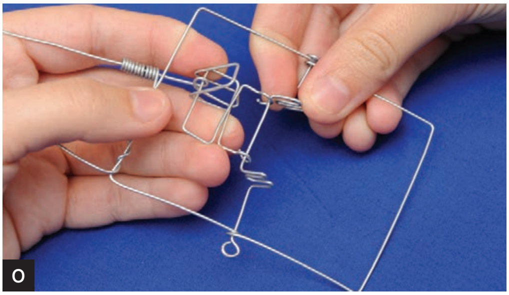
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Making Bar Soap

Wash your hands of the toxins found in commercial soaps.

By Alastair Bland

JUST WHERE AND WHEN HUMANS FIRST observed the chemical reaction between oil and potash is unknown. One legend says it was at "Mount Sapo" in ancient Rome, where a creek flowed over a deposit of wood ash and animal fats created by sacrificial fires for the gods. There's evidence that the ancient Babylonians, Egyptians, and Celts all developed soap — but regardless of who was first, it's clear that observing nature led people to re-create the chemistry of water, potash, and oil to produce the first liquid soaps.

Bar soaps were innovated in the 19th century, but soon after, the soap-making industry introduced problematic chemicals to the equation, such as propyl alcohol, limonene, benzaldehyde, and methylene chloride. Today, some soap ingredients are derived from animals rendered in factories, while others are known to be toxic, even carcinogenic, and contain byproducts of petroleum.

All natural, plant-oil-based soaps provide an eco-conscious alternative, but 2 downsides remain: the disposable packaging and the collateral damage of transportation. Fortunately, making soap at home is easy, and not much more complex than baking bread.

In its most basic form, soap consists of just 3 components — a strong base such as potash or lye, oil, and water. Potash (potassium hydroxide) is harder to find and is more conducive to liquid soap making, so we'll use lye (sodium hydroxide).

Blended at the right proportions and

Gregory Hayes

temperatures, these ingredients produce a chemical reaction called *saponification* which renders the lye, normally caustic and dangerous when mixed with water, entirely benign while breaking apart the oils and eliminating their cloying greasiness.

And although curing (allowing the soap to dry and harden) takes about a month, the first and most demanding steps take just 30 minutes for practiced soap makers.

Now consider that a year's supply can be made in a single batch; each bar will cost about a dollar; you won't risk exposure to any lingering poisons — and one by one they mount: the good and healthy reasons to free oneself from chemical industries and never buy soap again.

1. Set up a soap-making station in your kitchen.

Weigh your ingredients and place each in its own vessel. Water goes in the heat-resistant jar, and coconut oil goes in the saucepan.

2. Melt the oil.

Gently warm the coconut oil on the stove. The chunks of fragrant fat will melt into clear grease (Figure A).

3. Carefully add lye to water.

Open your doors and windows. Don your protective gloves and glasses, and slowly pour the lye into the jar of cold water. Stir with a steel spoon. A fast exothermic reaction will occur as the temperature shoots to nearly boiling and the mixture momentarily emits a plume of toxic fumes. Do not inhale over the jar. Insert a thermometer and watch the temperature as it slowly drops (Figure B). Your target reading is 80°F.

CAUTION: Lye is highly caustic and will burn skin and eyes. Wear protective gloves and goggles, and follow all directions on the container for safe handling of lye. Clearly Figure B outs us throwing caution to the wind.

4. Take the temperature.

Insert the other thermometer into the pan of melting coconut oil. When the oil is 90°F and

MATERIALS

To make larger batches, keep proportions exactly the same.

8 fl oz (1c) cold water
79g (0.176lb) sodium hydroxide (lye) Buy a jar of 100% lye drain cleaner at your local hardware store.
10½ fl oz (297.6g or 0.656lb) olive oil It needn't be extra virgin. The quality is irrelevant since you'll mix it into a lye-and-water chemical bath.
10½ fl oz (297.6g or 0.656lb) coconut oil found at natural foods stores in plastic jars or, preferably, in bulk. Buy organic or fair-trade if possible.
8g essential oils (optional) for fragrance and nutrients
½c steel-cut oats (optional) for abrasiveness

TOOLS

Kitchen stove
Digital scale capable of accurate measurements in grams
Safety goggles
Rubber gloves
Kitchen thermometers (2)
Glass jar, heat resistant, 40oz or larger
Saucepan, stainless steel for heating oils on stove
Spoon, stainless steel for stirring lye and water
Electric eggbeater, stick blender, or pedal-powered blender
Milk carton, or wooden box with parchment paper for a mold for curing
Knife for cutting and shaping bars

CAUTION: Do not use aluminum kitchenware. Lye and aluminum react to form flammable hydrogen gas and can cause fire or explosion.


A


B


C

liquefied, turn off the heat and add the olive oil (Figure C). The temperature of the blended oils should read 80°F.

5. Combine the liquids.

When both the lye water and oils reach 80°F, combine the two in the glass jar. The mixture will abruptly turn cloudy (Figure D).

6. Blend it all together.

Blend the liquid for roughly 15 minutes using either an electric eggbeater or stick blender (Figure E). You can also whisk by hand, though this will take about an hour.

However you approach it, your goal is saponification, which occurs visibly as the liquid thickens and turns opaque (Figure F). To test for it, lift the blender from the liquid and drizzle the soap across the surface. When droplets remain on the surface for a moment before sinking — known as *tracing* — it's done.

7. Add scents and scrubs.

If you're going to add fragrances, essential oils, or oats, now's the time. Add and mix — and do it fast, because the soap may be thickening more quickly than you realize.

Any additional ingredients must be all-natural to avoid fouling up the delicate chemistry of the saponification process.

8. Mold it.

Pour the soap into your mold (Figure G). Paper cartons should be thoroughly cleaned, and wooden molds should be lined with parchment paper. Cover the filled mold with a cutting board or coffee table book and set it aside for 1–3 days to harden.

9. Cut, cure, and wash up.

Lift the long soap block from the mold, peel away the parchment paper, and cut the brick into roughly 10 bars (Figure H).

Stand each bar on end to allow the most surface-to-air contact, and set them aside to cure undisturbed. Three weeks should do it, at which point the lye's causticity has fully neutralized, and your soap is ready.


D


E

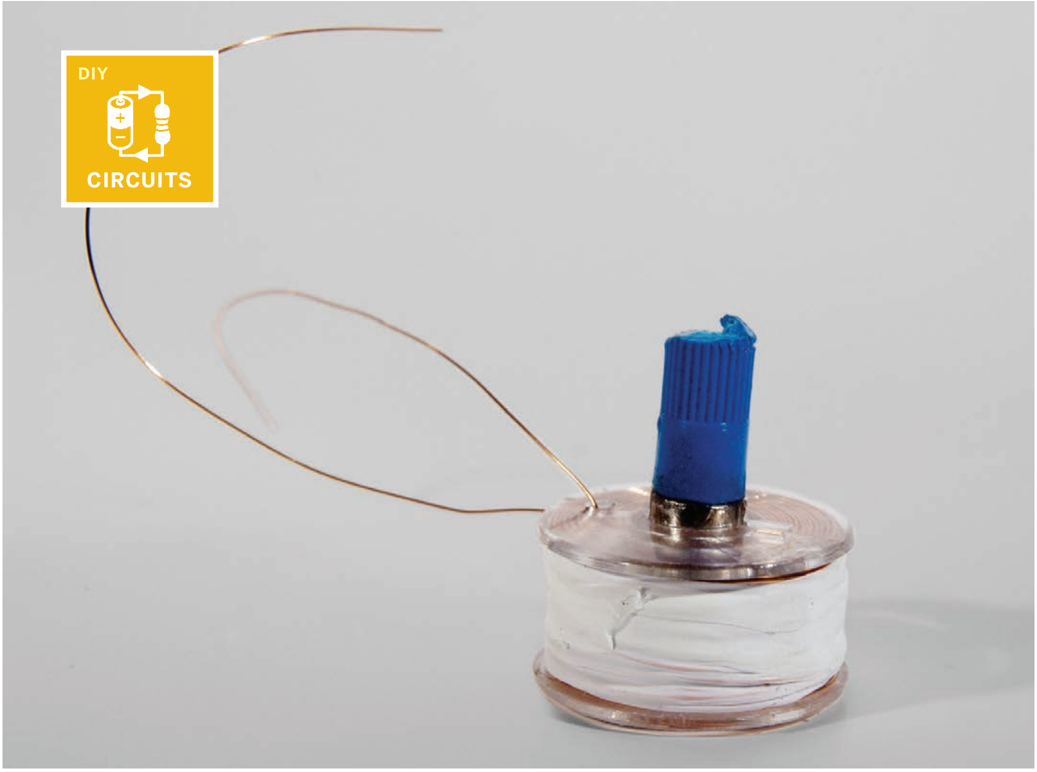

F

G


H

Congratulations. You can now wash your hands of the chemicals and toxins used by the commercial soap-making industry. Learn more at makezine.com/go/makesoap.

Alastair Bland is a freelance travel, food, and news writer in San Francisco. After graduating from UC Santa Barbara, he wandered through California by bicycle and Baja California by foot for two years before falling into journalism. Follow his latest travels at blogs.smithsonianmag.com/adventure.



The Bobbinator

Make inexpensive linear actuators out of sewing machine bobbins.

By Andrew Lewis

LINEAR ACTUATORS ARE MOTORS THAT work in a straight line. They're very useful for controlling valves and levers, building robots, and retrofitting old mechanisms for digital control. The simplest form of linear actuator has only 2 positions, while more complicated actuators can be positioned just like stepper motors and servos.

I needed 32 linear actuators for my latest project, and I was shocked to discover how much they would cost. After a little thought, I decided that I only needed simple on/off actuators, and I would try to make them myself using off-the-shelf parts.

Wind and Wrap the Bobbin

1. Place an empty bobbin onto the bobbin filler on the sewing machine. Feed the end of the copper wire into the hole at the top of the bobbin. I left about 1" of wire sticking out of the top, so I could solder the coil in place later.

2. Feed the wire through the thread guide nearest to the bobbin filler. Do not use the tensioning wheel or the other guides. Place the spool of wire somewhere that it won't snag, and run the sewing machine slowly. Watch the spool fill with copper wire (Figure A), and apply gentle tension to the wire with your hand. Don't grab the wire tightly, or you'll cut yourself.

3. When the bobbin is full, stop the machine. Hold the wire in place on the bobbin with your

Andrew Lewis

MATERIALS AND TOOLS

Bobbins, plastic, for sewing machine
Magnets, rare earth, 6mm diameter × 3mm
Rod, plastic, 6mm
Wire, copper, enamelled, 38 SWG (35.5 AWG)
PTFE tape aka Teflon plumber's tape
Thin plastic or laminated card
Epoxy glue
Cable cutters
Sewing machine

thumb. Cut the wire about 1" from the side of the bobbin, and then remove the bobbin from the bobbin filler. Remember to keep your thumb on the side of the bobbin, or the wire will unravel.

4. Wrap a couple of layers of PTFE tape around the side of the bobbin. Make sure that the wire at the side of the bobbin is roughly aligned to the wire poking out of the top (Figure B).

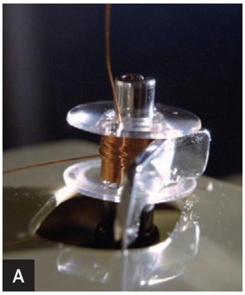
Add Plastic, Spring, and Magnet

5. Cut a circle of thin plastic and glue it to the bottom of the bobbin (Figure C). Make sure the hole through the bobbin is blocked off on the side opposite to the wires.

6. Take a short length of the copper wire, and wind it around a thin screwdriver shaft to make a small spring (Figure D). The spring should be about 4mm diameter, and about ¾ the height of the bobbin.

7. Glue a 6mm magnet onto the end of a length of metal or plastic rod. I needed about ½" of plastic rod, so I used the shaft from an old plastic potentiometer. Don't get too much glue around the edge of the shaft, or it may get wedged inside the bobbin when you fit it. Finally, add another dab of glue to the magnet, and glue it to the spring (Figure E). Fit the spring inside the bobbin center, and fix with a bit more glue.

You should now have a simple linear actuator that pulls the shaft inside the bobbin when you apply a voltage to the coil.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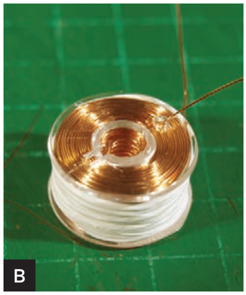
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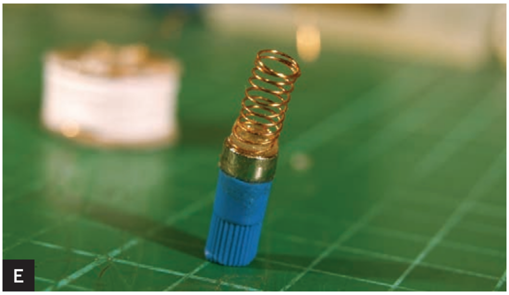

E

You can reverse the action of the actuator by reversing the voltage, and you can reverse the action of the spring by using a thinner shaft with a second piece of thin plastic as a washer on the end of the bobbin.

You can also use multiple coils to create a longer stroke for the actuator, and position the shaft by varying the current between each of the coils. I find that each coil has a resistance of between 8Ω and 9Ω, and works well between 6V and 12V. Increasing the voltage will up the power, but will also increase the heat generated by the coil. Experiment to find the maximum voltage for a particular application, and with long duty cycles, stick a thermal fuse next to the coil for safety's sake.

Andrew Lewis (andrew@monkeysailor.co.uk) is a keen artificer and computer scientist with interests in 3D scanning, computational theory, algorithmics, and electronics.

Easy Sunburst Guitar

Build a kit electric guitar and finish it like the pros.

By Steve Lodefink

ONE OF THE BEST WAYS TO LEARN ABOUT electric guitars is to build one of the many DIY guitar kits available. When it's done, you'll have not only a working instrument, but an understanding of how your instrument works. You'll know how to string it, adjust it, and set the action the way you like. You'll become your own guitar tech.

If you're an old hand with guitars, kits can be a low-cost way to get that "custom shop" Les Paul look you've coveted, for no more than the kit price, plus a bit of elbow grease.

Begin by Finishing

Kit guitar building has 3 phases. The first is to apply a finish to the wooden parts. Done right, this is 80% of the work. The second phase is assembly, which is really fun, seeing all the parts come together to become an electric guitar. Finally, there's "setup": adjusting the neck, pickups, action, and bridge to make the guitar sound and feel good.

The finish typically involves a base coat and a clear, protective top coat. For a classic "sunburst" finish, you don't need an airbrush; you can use 2 colors of spray paint for your base coat. Make sure your clear coat and base coat are compatible. Traditional guitar finishes are nitrocellulose lacquer, available in spray cans from luthier supply houses. Polyurethane will serve just as well. Acrylic finishes also work, but tend to be less durable.

1. Prep the parts.

Many guitar manufacturers have trade-marked their headstock shapes, so to protect

Steve Lodefink

against lawsuits, kit guitars often ship with large, blocky headstocks that kit builders must shape themselves. On the plus side, an unshaped headstock allows you to come up with your own signature design.

Use a coping saw or bandsaw to cut the headstock to your liking, then sand out the cut marks with 100-grit sandpaper. Follow up with 180, 220, and 400 grits.

Then mask the fretboard, edge binding (if any), or other areas you don't wish to paint, before moving on to the finish work.

2. Apply the sunburst finish.

2a. Spray the lighter color onto the guitar body (Figure A). Paint a couple pieces of scrap, too, for testing purposes.

2b. Make the mask. Trace the guitar body onto a sheet of cardboard. Cut the mask out a few inches inside your traced line.

2c. Test the mask. Position the mask an inch or so above a piece of scrap and spray the darker color around the edges. The overspray will find its way under the mask, creating a smooth gradient. Adjust the mask height until you get the burst effect you're after.

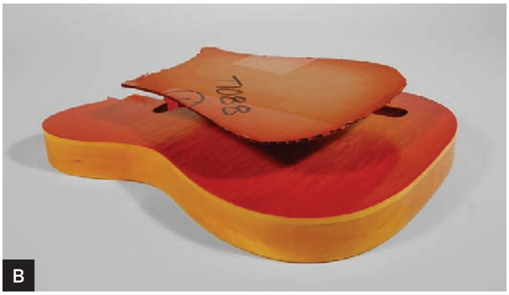
2d. Spray the darker color on the guitar top. Once you've got your technique down, position the mask over the guitar top and spray around the edges as you practiced (Figures B–C, and Figure D, following page). Repeat for the back of the guitar, if desired. Give it plenty of time to dry before going on.

2e. Apply the top coat. To get that smooth, glossy shop-window finish, expect to spray on about 10 coats of clear. Once the top coat has thoroughly dried, wet-sand the surface to 1500 grit, rub with polishing compound, and give it a final wax and buff (Figure E).

3. Assemble the parts.

First, attach the neck to the body. With Fender-style guitars, this means drilling holes, then using wood screws and a backing plate


A


B


C

to join the parts. Gibson-style models often have a "set neck," which has a pre-cut dovetail joint for gluing. Glue a set neck in place before applying the final coats of clear finish.

The rest of the assembly will just be a matter of correctly locating the bridge and installing the pickups, control knobs, tuning machines, input jack, switches, pots, and pick guard. All the hardware should be included with the kit. Finally, install the strings.

4. Adjust for sound and feel.

4a. Adjust the neck. This is done by turning the built-in steel truss rod to slightly bow the neck forward or back. "Relief" is forward bow of the neck, while "back bow" is the opposite condition. The neck should have just enough relief to allow the strings to clear the frets without buzzing, but not so much as to cause an overly high action. Turn the truss rod clockwise to decrease relief, or counter-clockwise to increase it.

4b. Adjust the string height. This is known as "setting the action." The bridge will have adjusters to raise or lower the strings in relation to the fretboard. Some players prefer a high action, but most prefer it as low as possible without buzzing.

4c. Adjust the pickup height. The gap between the strings and the pickups is best adjusted by trial and error. Start with a 3⁄16" gap. Use the pickup mounting screw to experiment until you get a sound you like.

4d. Adjust the intonation. First, tune the guitar. Then, starting with the low E string, compare the pitch of the open string to the pitch at the 12th fret. If the fretted note is flat, use the bridge saddle adjuster to make the string "longer." If sharp, make the string "shorter." Do this for all 6 strings. You shouldn't have to readjust the intonation unless you change string gauge or brand.

Steve Lodefink is a designer by day and a tinkerer by night. Building small projects to learn new skills and discover new materials is both his hobby and his therapy.


D


E


F

1+2+3 Paper Clip Record Player

BY PHIL BOWIE

You can make it!

GOT A TURNTABLE THAT STILL TURNS? Got an old vinyl record? Make this pocket player in a few minutes for less than a penny.

1. Prepare the paper clip.
Unbend the paper clip and reshape it into a hook. Using fine-grit sandpaper, sand the long end to a fairly even, slightly dull point.

2. Join the paper clip and foam peanut.
Insert the hook-shaped clip into the peanut as shown.

3. Play a record.
Place an old 45rpm or 33rpm LP record (one you don't care about scratching) onto a turntable, and turn it on. Without pressing down too hard, carefully hold the pointed end of the paper clip in a groove as shown. You'll hear the music reproduced in remarkable fidelity, as the closed cells in the foam peanut act like a cluster of tiny amplifying speakers.

Going Further

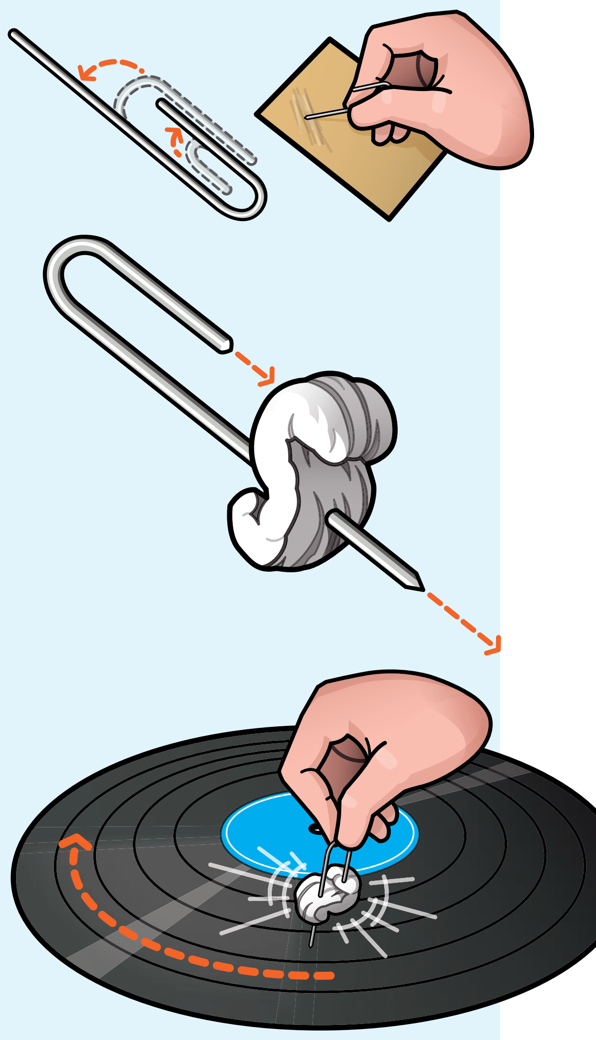
For mellower sound, use a softer (but still closed-cell) foam peanut. For more volume, add another peanut alongside the first one, like a peanut kabob, and apply a hair more playing pressure. For more sophistication, as when playing classical selections, use an actual steel record needle with the foam peanut, available dirt-cheap online.

To experiment further, try straightening the paper clip and taping it firmly to the side of a small polystyrene drinking cup with a thin, translucent, plastic top snapped onto it (a half-pint deli-style container works well, too). It makes a remarkably loud speaker.

Don't have a turntable? Turn a lazy Susan into a makeshift turntable: oil the ball bearing in the base, place a piece of rubber nonskid shelf liner on the top surface, and center a 45 record on top. You have to spin it fairly well to get enough rpm, but it does work!

YOU WILL NEED

Paper clip, standard #1 size
Polystyrene foam packing peanut, rigid
Sandpaper, fine-grit

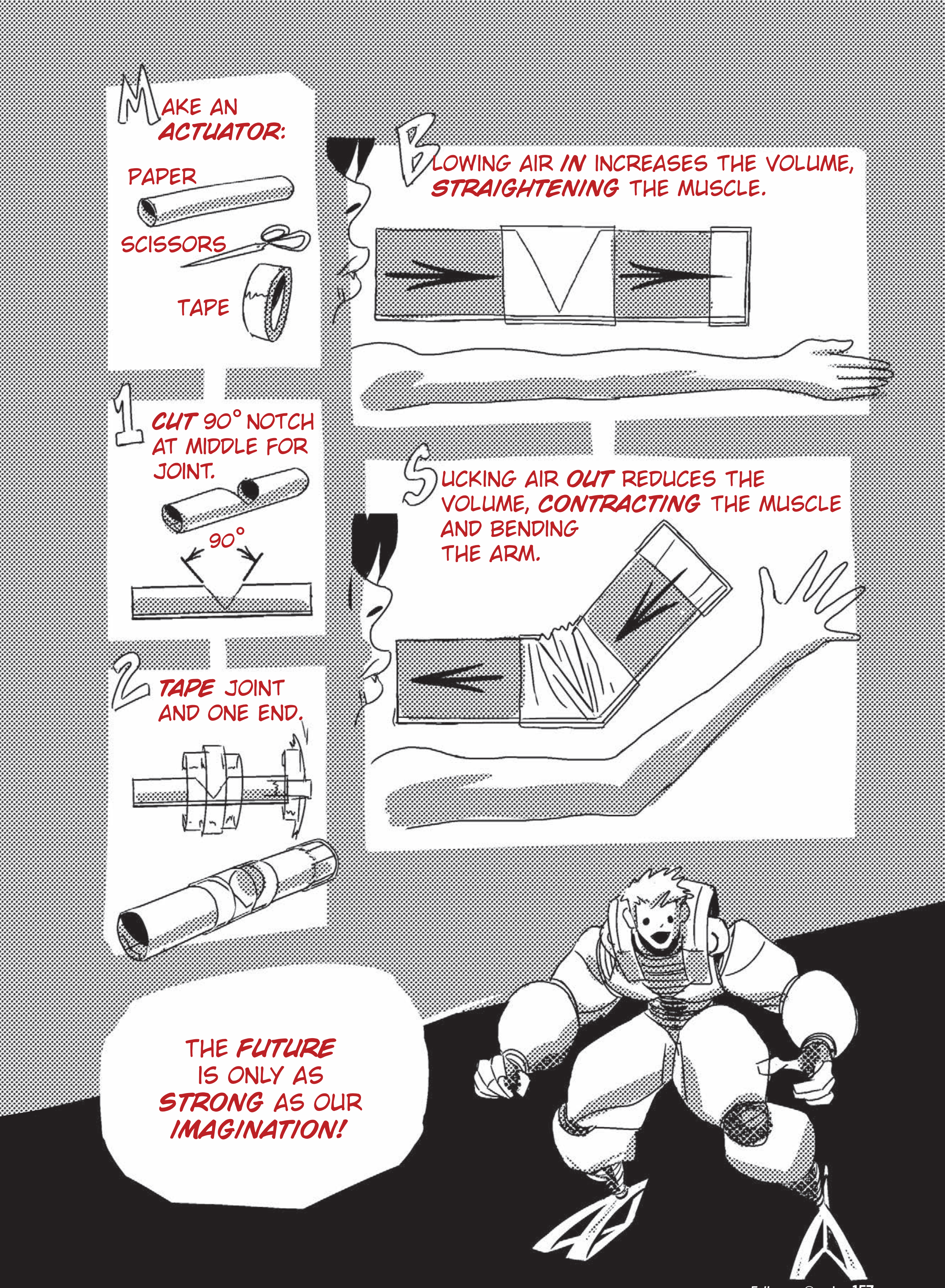


Note: It's important to hold the player by the paper clip wire to get the best sound. If you hold the peanut, your fingers tend to dampen the sound.

Damien Scogin

Phil Bowie is a boat captain, pilot, motorcycle rider, and lifelong freelance writer of articles and fiction. philbowie.com

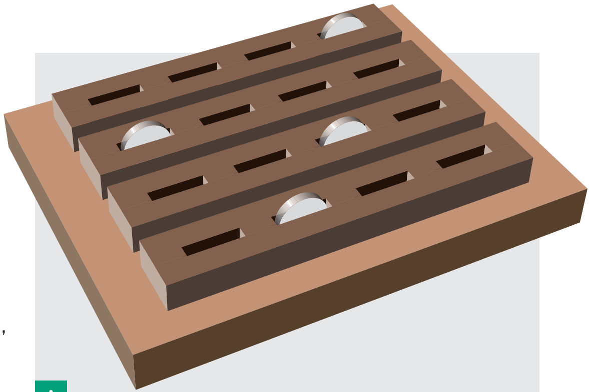

HOWTOONS.COM
THE PNEUMATIC KIDS
WOW!
WE WOULDN'T NEED TECHNOLOGY IF SUPERPOWERS WERE REALLY POSSIBLE!
TO GAIN EXTRA STRENGTH, WE NEED MORE MUSCLES, OR "ACTUATORS" AS TECHIES CALL THEM.
TO POWER OUR MUSCLES, WE CAN DEVELOP NEW PNEUMATIC TECHNOLOGIES, OR AIR-POWERED MUSCLES.
WE CAN MAKE THESE PNEUMATIC MUSCLES BY USING PRESSURIZED AIR CANISTERS CONNECTED TO A NETWORK OF HOSES THAT ADD AND SUBTRACT AIR, MOVING THE 23 DIFFERENT MUSCLES OF THE ARM.


MAKE AN ACTUATOR:
PAPER
SCISSORS
TAPE
1 CUT 90° NOTCH AT MIDDLE FOR JOINT.
90°
2 TAPE JOINT AND ONE END.
BLOWING AIR IN INCREASES THE VOLUME, STRAIGHTENING THE MUSCLE.
SUCKING AIR OUT REDUCES THE VOLUME, CONTRACTING THE MUSCLE AND BENDING THE ARM.
THE FUTURE IS ONLY AS STRONG AS OUR IMAGINATION!

By Charles Platt, Author of *Make: Electronics*

Improbable Slots Carnival Game

Customize it and calculate your odds of winning the big teddy.



A

Charles Platt

AT A COUNTY FAIR LAST SUMMER, I saw an interesting new way to lose money. Players placed 4 quarters among 16 slots in a board, putting one coin in each row, as shown in Figure A. Each coin made an electrical connection between 2 contacts at the bottom of its slot. If you managed to arrange the coins in a secret winning combination, the coins completed a circuit, a light came on, and you won a monster-sized teddy bear.

While I was watching people play, I saw someone win. After she collected her prize, she decided to play again — and found that the previous winning combination didn't work anymore. The owner had secretly changed it, probably with some wiring like the schematic in Figure B, where a rotary switch can select 4 different preset combinations. (To learn more about rotary switches, see page 160.)

It seemed to me that constructing a replica of the game would be easy enough, although I wanted a more precise way to make contact with the coins. I cut pairs of brackets from a length of aluminum angle, ½" by 1⁄16" thick, which I found at Home Depot. I used ½" #3 machine bolts to attach each bracket to a piece of plastic, although plywood would be just as good.

Because I wanted some flexibility, I sandwiched a thin piece of rubber under each bracket, and didn't screw them down too tightly. Inserting tap washers would produce the same effect. Underneath, I clamped #20 solid-conductor wire around each bolt.

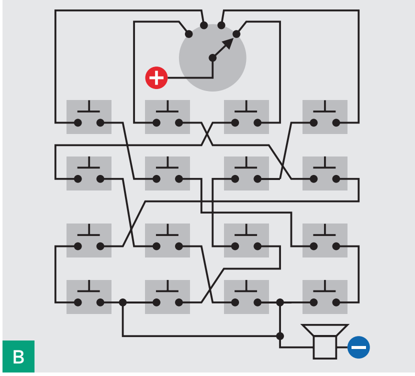
If you use this system, drill ample-sized holes so that you can nudge the brackets into exactly the right position. They should grip a coin tightly when someone pushes it in. Figure C shows one row of 4 slots.

I wondered if the game would be more interesting with a different number of slots or coins. How would this affect the probability of winning?

Calculating the odds at the county fair was easy. There were 4 ways to put a coin in each row, and 4 rows, so the total number of combinations was 4×4×4×4 = 256. Therefore,

MATERIALS AND TOOLS

Plywood, ¼"; or plastic sheet, ⅛"
Aluminum angle, ½" legs × 1⁄16" thickness, at least a 2' length available at Home Depot and hardware stores
Thin rubber sheet or tap washers
Machine screws, #3 or #4 × ½", with nuts and washers (32)
Hookup wire, 20 gauge or similar
Battery, 9V
Battery snap connector, 9V
Beeper, piezoelectric
Rotary switch, single pole, with at least 4 positions
Soldering iron and solder A low-wattage iron will be insufficient to attach the wires to the screws. Use a 30-watt iron or higher.



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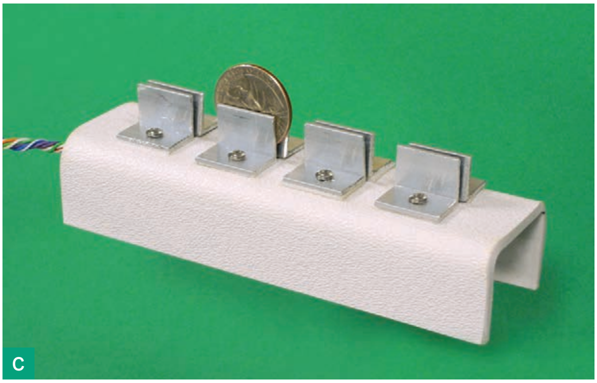
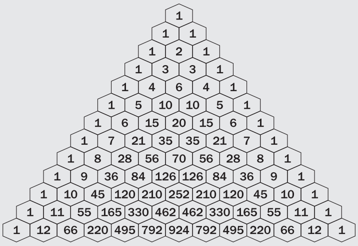


C

$$\frac{n!}{k! \times (n-k)!}$$

D



E

Fig. A: (Opposite) Simplified view of a coin game at a county fair. When placing 4 coins, 1 per row, the odds of finding a single winning combination are 1 in 256.

Fig. B: Rotary switch (top) selects among 4 secret winning combinations in the county-fair coin game.

Fig. C: One row of 4 coin slots made from ½" aluminum angle. You'll need 4 rows to replicate the original coin game — but see text for other options.

Fig. D: Formula for figuring the number of ways to choose *k* (coins) options from a total of *n* (slots). Each exclamation point denotes a factorial number.

Fig. E: Pascal's Triangle can be used as a lookup table for probabilities, and has many other interesting applications.

each time you played, you had 1 chance in 256. Since the stake for each game was $1, the game owner would take an average of $256 before he had to give away that oversized bear (not a bad profit margin!).

Suppose I wanted a different configuration — say, 5 coins placed among 9 slots. I would have to get rid of the rule about placing just one coin in each row. Really, a player should be able to distribute the coins in any pattern at all.

This makes calculating the odds more complicated, but fortunately the problem falls into a general category that mathematicians dealt with centuries ago. It entails choosing a limited selection from a larger range of options. Suppose the number of options (the number of slots in the game) is represented by letter *n*, and the size of the selection (the number of coins) is *k*. The formula in Figure D tells us how many combinations will be possible.

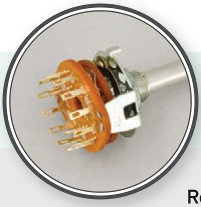
If you're wondering what the exclamation points are all about, they are used in math to indicate a *factorial* number. A factorial 3 (written as "3!") is 3×2×1, while factorial 4 (written as "4!") would be 4×3×2×1, and so on. (Search for "factorial combinations" online if you want to find out why the formula works. For an introduction, see makezine.com/go/permutations.)

The trouble is, doing all those multiplication sums in factorials is a real chore. Isn't there a simpler way? As it happens, there is. It's called Pascal's Triangle (Figure E). Blaise Pascal, the great mathematician, discovered many interesting properties of his triangle, and if you look it up online, you'll find yourself getting into something very deep and rather difficult called the binomial theorem.

For our purposes, we'll just use the triangle as a lookup table. Search down the left side for a row beginning with *n* (your total number of slots). Ignore the number 1 preceding each row. Now move to position *k* along the row (remember, *k* is the number of coins). The number you end up with is the number of possible combinations.

For example, suppose you have 12 slots in your game, and 5 coins. Go to the row on the triangle beginning with 12, go to the fifth

ABOUT ROTARY SWITCHES



Rotary switches aren't used as often as they once were. Introductory books often don't explain how to use them, so here are a few fundamentals.

A *rotor* attached to a shaft connects with contacts around it, one at a time, when the shaft turns. The rotor is the *pole* of the switch. If there are 6 contacts, the switch has 6 *positions*. Switches are usually available with 2 to 12 contacts, although some have more.

Often a second set of contacts is arrayed opposite the first, and a second rotor makes contact with them. This type of switch has 2 poles on one *deck*, and you have to check the manufacturer's data sheet (or use your multimeter) to figure out how the solder tabs on the outside connect with the contacts inside.

Many rotary switches have multiple poles and/or multiple decks. If you can't find a switch with the number of positions you want, you can limit the positions with a movable pin or lug. So, an 8-position switch can be set to allow only 7 positions.

If a rotor makes a connection with the next contact a moment before breaking the connection with the previous contact, this is known as a *shorting* switch. In a *non-shorting* switch, there's a tiny gap between one connection and the next.

Rotary switches have been displaced by cheaper, smaller *rotational encoders* in many applications, especially in audio equipment, where a knob turns freely to control volume or choose modes. The encoder contains 2 pairs of contacts that open and close slightly out of sync. You need a microcontroller to interpret the pulses and figure out which way the knob is turning.

In hobby electronics, we may not want the hassle of programming a microcontroller, and a plain old rotary switch will work fine. Just make sure you choose one that's capable of switching the voltage and current in your circuit, so you don't degrade the contacts by allowing sparks to occur.

position, and you reach 792 as the number of combinations. If only one of them wins the game, the chances of someone hitting it are 1 in 792. Personally, I'd be reluctant to play a game with such bad odds. If I was running my own little casino, I might prefer a game with, say, 2 coins among 5 slots, giving odds of 1 in 10. Taking in 50 cents a game, I could give a $4 prize and still make a 20% profit.

Getting back to the triangle — you'll have noticed that the number 12 begins the bottom row. What if you want to figure the odds in a game with more than 12 slots? No problem! Each new row is created by using a very simple rule. Every number in the triangle is established by adding together the pair of numbers above it. So, you can extend the triangle downward as far as you want.

Now you can design your own game with any number of slots and coins, to create any level of difficulty. Your only additional problem is how to add a rotary switch to set your secret winning combinations. Your exact schematic will depend on your slot/coin configuration. I'm betting you can figure that out.

I have just one more suggestion for an enhancement. How about changing it to a 2-player game, using on-off toggle switches instead of coins? This would suit people who don't approve of gambling. And to make it more interesting, you could revise the rules so that the 2 players take turns to flip switches, continuing for an unlimited number of turns until one person finally wins by hitting the secret combination.

This really requires a new secret combination for every game. In fact, your game should create its own combination randomly from all those that are possible. A microcontroller would be the way to do this. The switches would be its inputs, and it would scan them until it "sees" the winning combination and activates an LED or a beeper. If you've read my previous columns in which I used microcontrollers to choose random numbers, you should be able to create this circuit. You'll also find an introduction to microcontrollers in my book *Make: Electronics*.

+ *Make: Electronics* book at the Maker Shed: makezine.com/go/makeelectronics

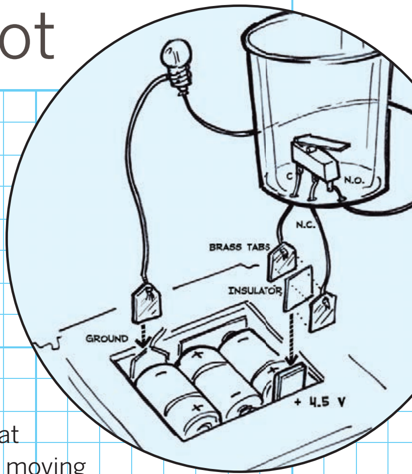
Charles Platt is the author of *Make: Electronics*, an introductory guide for all ages. A contributing editor of MAKE, he designs and builds medical equipment prototypes in Arizona.

Gregory Hayes

TOY INVENTOR'S NOTEBOOK
Invented and drawn by Bob Knetzger

You can make it!

Root Beer Pong Bot



WHEN MAKING PROTOTYPES, I OFTEN "kit bash" broken toys to harvest useful components like motors, gear trains, or radio-control transmitters and receivers. No need to reinvent the wheel — literally!

SmartLab's new toy robot, ReCon 6.0 Programmable Rover, is a tempting hack. Open it up and you'll find lots of cool stuff inside, including a nifty dual-motor drive module with built-in optical wheel counters (go to makeprojects.com/v/29 for photos and details).

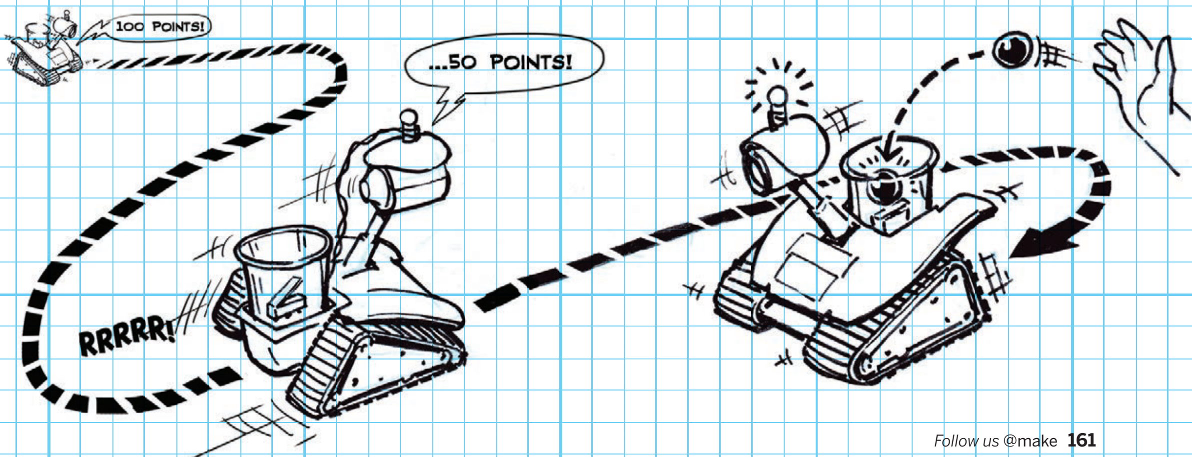
Here's a "noninvasive hack" that takes advantage of ReCon's cool features while adding a fun new function to make a "Root Beer Pong Bot."

I wanted to add a sensor to control ReCon in real time. Fortunately the toy's nonvolatile memory retains your program even when the batteries are removed. So I used this feature to add a kill switch: a thin, double-sided contact that slips in between the batteries and ReCon's battery contacts. This "power stealer" circuit works with a cup-mounted single-pole single-throw (SPST) micro lever switch that normally routes the power right back to ReCon — but if the switch is closed, power goes only to a bulb. When you toss a ball into the cup (à la Beer Pong), ReCon stops in its tracks and the bulb lights up — that's a "kill."

Next I created a simple program that turns ReCon into a moving target game. As it follows a programmed path across the floor, it also plays a series of sound messages announcing an ever-decreasing point jackpot. The sooner you "kill" ReCon by tossing the ball into the cup, the higher your score! Go to makeprojects.com/v/29 for a listing of my program. You can also post your programs or other noninvasive hack ideas there.

And when you're done with this non-invasive hack, just slip the wires out from the battery compartment, and your toy is back to original factory condition!

Bob Knetzger is an inventor/designer with 30 years' experience making all kinds of toys and other fun stuff.



Bend PVC like a champ, outsmart your cards, geek out on Lego, and fly a tiny chopper.

TOOLBOX

MILWAUKEE M-SPECTOR AV M12 CORDLESS MULTIMEDIA CAMERA

$299 **milwaukeetool.com**

The Milwaukee M-Spector camera is a rugged, digital inspection scope that helps you see things you'd otherwise need x-ray vision to espy. The M-Spector adds quite a few features, such as the ability to snap photos and shoot video (and audio) of your inspections.

The provided 17mm-diameter cable is small enough to snake into tight places — I fished it into a conduit to see which CAT-5 cable was binding on the others. I've seen other manufacturers offer a small hook or magnetic tip accessory, which Milwaukee does not. Might not be too hard to improvise, and could be useful for grabbing lost parts. The images weigh in at 1280×960 pixels, and while they aren't as clear as I'm used to from my cellphone, they're just fine considering they're being taken in a small, dark place 40" away from the sensor.

I think the M-Spector will find most of its use when I'm doing wiring work, but it's also incredibly handy for other household repairs and project work. Plus, it sure is fun poking around under furniture and inside machines. This is the kind of tool to let your friends know you've got, so they can borrow it before they go ripping open an entire wall.

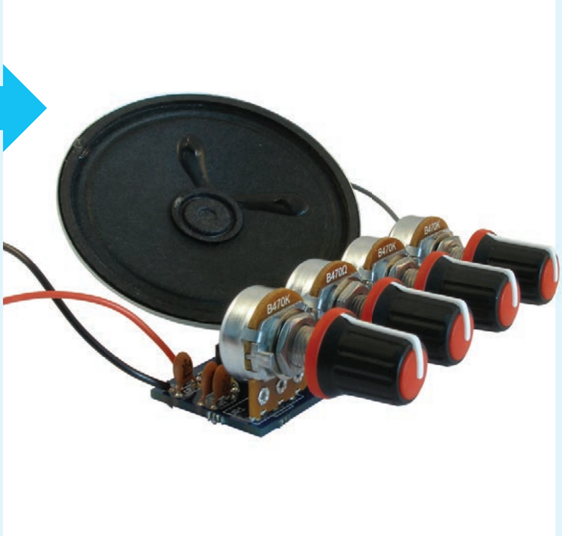
—John Edgar Park

+ For a more detailed review, see makezine.com/go/mspector.

Vibrati Punk Console

£20 (about $27) **lushprojects.com/vpc**

A gloriously noisy spin-off of the legendary Forrest Mims Atari Punk Console, the VPC emits countless variations of buzzes, squawks, and other sassy noises. Creator Iain Sharp added a low-frequency oscillator to the mix, creating a much more diverse set of sounds than Mims' synth. Sharp claims that a newbie solderer can complete it in only a couple of hours, making it great for soldering classes. Best of all, it comes with a speaker, allowing you to begin playing as soon as you finish the build. *—John Baichtal*



PVC Bendit

$199–$399 **pvcbendit.com**

PVC Bendit calls itself "the ultimate tool for bending PVC," and I completely agree. When I opened the box, I was greeted with a strange assortment of flexible steel conduit, segments of pipe insulation split lengthwise, and other odds and ends. But as soon as I popped the CD into the computer and watched the highly amusing videos, the form and function all became perfectly clear to me.

Of course I had to give it a try, so I slipped a length of PVC over the heating element, wrapped the insulation around the setup, and proceeded to smoke out MAKE Labs. After opening a few windows and turning on a fan, I tried again, and soon the once-straight and rigid PVC pipe was as floppy and loose as a wet noodle. I had a perfect opportunity to really test out the PVC Bendit making corrals for drummer bots, and it performed well beyond my expectations. *—Daniel Spangler*

C.H. HANSON AUTOMATIC LOCKING PLIERS

$20 **chhanson.com**

Traditional locking pliers are quite versatile, but their thumb-screw jaw adjustment can be a bit finicky. These aptly named pliers auto-adjust to whatever size part needs to be gripped.

Clamping pressure must be preset via a small screw, providing a consistent grip, even when clamping objects of different sizes. (I have found that they require two hands to close when gripping larger objects.) Like many European-made locking pliers, there's a no-pinch clamp release lever that's easier on the hands. *—Stuart Deutsch*

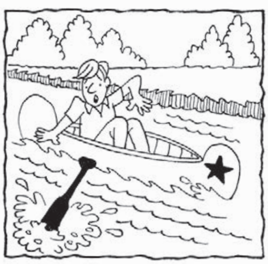
MAKEDO

$25–$50 makershed.com

MakeDo is a unique set of reusable connectors for creating things from the stuff around you. Reuse items like cardboard, plastic, and fabric to create structures, costumes, furniture, and decorations. When you're done, just pull your creation apart and reuse the connectors. Everyone will find a new use for them. This incredibly versatile and addictive building system is only limited by your imagination! Available in 65- or 170-piece sets.

—Michael Castor

Eureka! By Roy Doty
Danger!



VPN1513 GPS Receiver Module

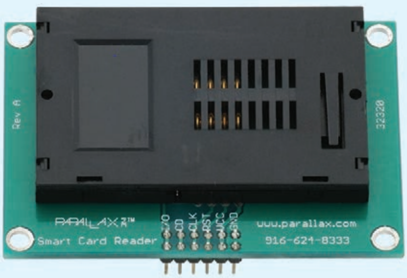
$60 parallax.com

In the world of hobby robotics, GPS and microcontrollers go together like peanut butter and jelly. But if you want to add GPS to your project, you need to locate a compatible device, then work out the interface with your MCU. Now Parallax introduces the combination VPN1513 GPS receiver and Propeller mini dev board, joining these two resources in one convenient unit.

The GPS chipset is capable of tracking up to 20 satellites, with observed lock-up time of 48 seconds from cold boot and 1 second from hot boot, as specified. Ample free documentation can be downloaded from Parallax, including the module schematic, default Spin source code, and libraries to assist in writing your own programs. It's ideal for developers of all experience levels.

Smart Card Reader/Writer Module

$10 parallax.com



What's (on that smart card) in your wallet? Readers for magnetic stripe and RFID cards abound, but you don't see many smart card readers for the hobbyist market. Parallax has a smart card reader/writer module designed for use with their Basic Stamp and Propeller microcontrollers. The software is open and well documented, allowing porting of the code for use with Arduino or other platforms. In addition to basic read ops, data can also be written to unlocked compatible cards. With this module and Basic Stamp 2 interfaced with a PC, I was able to read data from a photocopy control card. Its low cost and simple interface make it easy to incorporate smart cards in your microcontroller projects.

—L. Abraham Smith

Uniden Clock Radio Base Scanner

$140 **uniden.com**

> With its large amber screen, the analog 370 offers a number of interesting features.

While we all enjoy the various bells and whistles that today's modern radio scanners have to offer, there are indeed times when simplicity reigns supreme. What many people — both hobbyists and general consumers alike — could make use of is a relatively inexpensive all-in-one appliance. Enter the Uniden Bearcat BC370CRS.

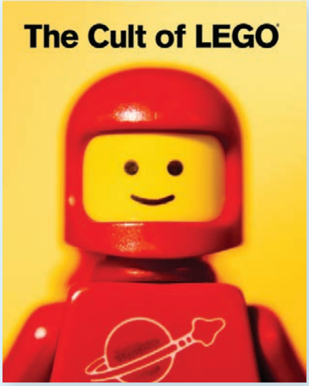
With its large and optionally backlit amber screen, the analog 370 offers a number of interesting features, including reception of NIST signals for automatic setting of its internal clock, an alarm clock with snooze, SAME alert activation for NOAA broadcasts, Emergency Alert System (EAS) alerts for AM/FM/TV broadcast channels, and a 300-channel/10-bank conventional scanner tossed in for good measure. All of these features are packaged in a radio that measures only a little bit larger than the form factor of the typical weather receiver.

—Joseph Pasquini

ENERGIZER LED FOLDING LANTERN

$25 **energizer.com**

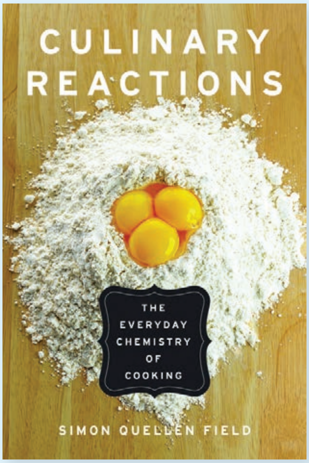
This solar- and battery-powered LED lantern is great for camping trips or simply in case of emergency. Energizer claims it'll run 135 hours on its three D batteries, or you can deploy the huge solar panel to charge it, yielding 2.5 hours of light on 5 hours' charging time. The solar panel sets this product apart from the competition. It covers the entire back of the lantern, and can be flipped up to catch the most rays, allowing it to charge on relatively dim light. The LED enclosure can also be adjusted, allowing you to use the device as a flashlight or to light up an entire room. A third option lets you use only a 5-lumen amber LED as a reading light. *—JB*



Let Go My Lego

***The Cult of Lego* by John Baichtal and Joe Meno**
$40 No Starch Press

Did you know that the only way to make a completely nude minifig is by using the torso and legs from a classic Space astronaut? This playful, comprehensive tome leaves no brick unturned in the world of Lego. Baichtal and Meno cover everything from Lego history to fake Lego, inspirational Lego projects massive and minute, fan profiles, organizational tips, events, publications, and tons more. Wanna know how best to pimp your minifig? They've got you covered. Thanks to the fan glossary, I now know the difference between an AFFOL and a NLSO. Between the visually striking full-color pages, the conversational writing style, and the infectious enthusiasm, whether you're a Lego devotee or not, this invitation to geek out is irresistible. The cover alone will make your coffee table smile. *—Goli Mohammadi*



Food Science

***Culinary Reactions* by Simon Quellen Field**
$17 Chicago Review Press

This book teaches science through cooking and cooking through science. With chapters on measuring, weighing, and scaling recipes up and down, you learn why some recipes work and some don't. Explorations of emulsions, protein chemistry, and oxidation give you a deeper understanding of processes foodies take for granted. The recipes are most often embedded within the explanation, so you suddenly realize that you just learned how to bake a perfect loaf of bread while reading about foams. Full of charts, step-by-step photos, structural formulas, and amazing recipes (the cherry cream cheese has me drooling), you will become a better cook without even trying. *—Arwen O'Reilly Griffith*

New from MAKE and O'Reilly

***Making Things See* by Greg Borenstein**
$32–$40 O'Reilly Media

Whether you're a student, hobbyist, gamer, or hardware hacker, this book gets you running with several Kinect projects and gives you the skills and experience you need to build your own creative projects with this magical 3D computer vision technology.

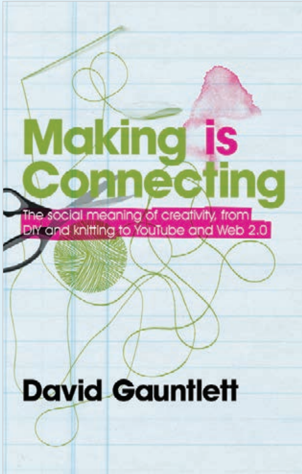
Make and Do

***Making Is Connecting* by David Gauntlett**
$20 Polity Books

David Gauntlett's argument — that creating things brings fulfillment and social connectivity to life — won't be earth shattering to any committed maker, but his thoughtful, well-argued polemic is nonetheless worth reading. A touch academic at times (it's littered with footnotes and references), it's still an enjoyable read.

The book is a perfect starting point for anyone wishing to learn more about everything from Ruskin and Morris to happiness theory and social capital, and from Web 2.0 to punk DIY. Gauntlett ends with a number of hopeful scenarios in which we transform from a "sit back and be told" culture to one of "making and doing." He argues that it won't be easy, but arming yourself with the knowledge in this book is a good first step.

—AOG



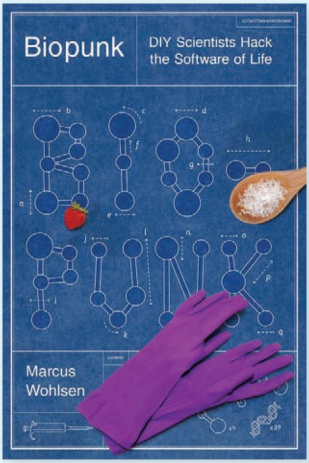
Hack Your Body

Biopunk: DIY Scientists Hack the Software of Life
by Marcus Wohlsen $26 Current

AP reporter Marcus Wohlsen set out to research the rise of home biotech: its roots, evolution, and implications on the future. Based on the view that scientific developments and advancement often get hamstrung by politics and bureaucracy, a growing number of biologists are conducting their research outside of traditional institutions, in home or community labs.

This book is laden with fascinating snapshots of the biotech innovators leading the charge, highlighting the humanity and passion that drives them. Biotech hackerspace (read: community biology lab) BioCurious' cofounder Eri Gentry sums up the ethos best: "Biotech is for everybody. You can make a difference if you have that right intention, if you have that passion that drives you. If you have that community and access to tools, the world is your oyster."

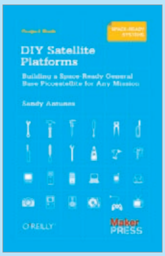
—GM

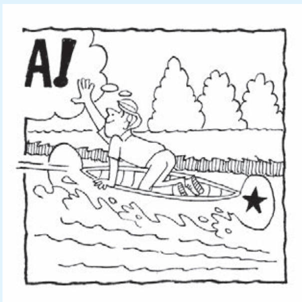


DIY Satellite Platforms by Sandy Antunes

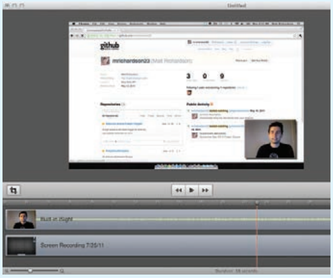
$5 O'Reilly Media

Can any hobbyist build a satellite? This DIY guide steps you through designing and building a base picosatellite platform tough enough to withstand launch and survive in orbit.





TOOLSDAY ROUNDUP



For your weekly tool fix, check out makezine.com/go/toolbox.

Handeze Therapeutic Gloves

$20 **handeze.com**

I bought these gloves from a medical supply store in 1997 even though I was convinced they were a gimmick. I was wrong. I instantly became sold on them and have never been without a pair since. They provide very comforting wrist support and "massage" your hands as you work. If sized properly, they'll seem too small and tight for the first day or so, but they'll stretch a little for a proper, firm fit.

—Gareth Branwyn

ScreenFlow

$99 **telestream.net**

Documenting a technology project that involves the computer can feel a little tedious, but glazing over details leaves many people feeling intimidated. Recording a screen capture is an excellent way to show the process; ScreenFlow helps you produce and share high quality screencasts with little fuss.

The editing features in ScreenFlow are surprisingly powerful. But the best thing about it is its nondestructive editing. No matter how you modify your screencast within ScreenFlow, the source footage is left untouched. Another killer feature is its ability to output to a wide variety of video formats. Initially, I wasn't sure if I should sink $99 into a screen-capture application when cheaper options exist, but it's a great value.

—Matt Richardson

Gilmour 528T Solid Brass Twist Hose Nozzle

$8 **amazon.com**

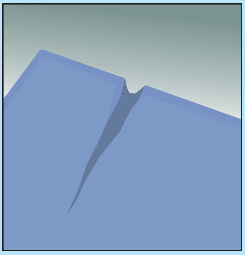
I come from a gardening family and have used many, many different spray nozzles in my life. Some worked well and some did not — but without exception, they didn't last. This nozzle is built to last. It has only two major parts, both machined from solid brass, which will never rust.

Twisted fully open, the nozzle produces a powerful single-jet blast, even with my middling water pressure. As you twist it closed, the jet spreads into a smooth conical fan, much better for watering plants that you'd rather not blast into pieces. But the price is the icing on the cake. I got mine from Amazon for $8 with free shipping, and loved it so much I bought three more.

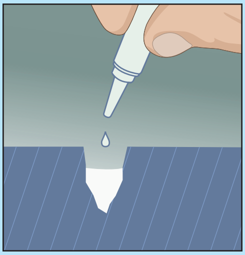
—Sean Michael Ragan

Tricks of the Trade By Tim Lillis

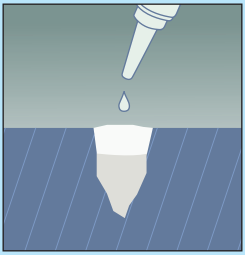
Putty that crack



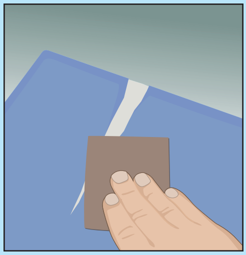
Have an imperfection or crack in a plastic part? George Schnakenberg at infinitecollective.com has you covered.



Put a small amount of baking soda into the cavity. Drip some cyanoacrylate (aka Krazy Glue) into the powder until saturated.



In deep cavities, such as the one shown, you may want to build up layers of the mixture to make sure you're getting good coverage.



Sand or scrape away any excess glue, then paint the fill if you like. For best results, experiment on some scrap before working on your final piece.

Have a trick of the trade? Send it to tricks@makezine.com.

Syma S107G RC Helicopter

$25 symatoys.com

If you're still on the fence about joining the micro-helicopter revolution, let me help you over. My kids and I have been through a few sets of Air Hogs helis, and while they were neat at first, they actually aren't that controllable.

Recently, we got a Syma S107G and were blown away. An absolute novice will be able to actually control this indoor helicopter, directing it around the room at will. The rock-solid hovers and smooth turns come thanks to an on-board stabilizing gyroscope, a feature that sets the Syma apart from earlier low-dollar micros. The counter-rotating main rotors and vertical tail rotor provide lots of stable thrust and control.

The build quality is pretty astounding as well, with an all-aluminum airframe, twin motors, and lots of screw-mounted, replaceable parts. Now's the time to get on the stick.

—Steve Lodefink

John Baichtal writes for MAKE, makezine.com, and geekdad.com.

Gareth Branwyn is editor-in-chief of makezine.com.

Michael Castor is the evangelist for the Maker Shed (makeshed.com).

Stuart Deutsch is a DIYer and maker who reviews tools at toolguyd.com.

Arwen O'Reilly Griffith is staff editor at MAKE.

Goli Mohammedi is senior editor at MAKE.

John Edgar Park is a frequent contributor to makezine.com.

Joseph Pasquini is an avid amateur radio operator and scanner listener.

Sean Michael Ragan comes from a long line of toolmakers and blogs at makezine.com.

Matt Richardson is a technophile, tinkerer, and co-host of *Make:* Live.

L. Abraham Smith works with open source hardware every chance he gets.

Daniel Spangler is one of MAKE's awesome engineering interns.

✱ Want more? Check out our searchable online database of tips and tools at makezine.com/tnt.

Have a tool worth keeping in your toolbox? Let us know at toolbox@makezine.com.

HEIRLOOM TECHNOLOGY
By Tim Anderson

Instant Cozy Kimono Robe

Everyone loves this robe, and there's room in it for everyone!

WHEN I WAS A KID IN AKITA IN NORTHERN Japan, friends gave us a couple of traditional kimono robes that were extremely simple and extremely cozy. It's amazing how little cutting and sewing it takes to make one of these — it's more garment for less work than you would think possible. You'll want to make all your blankets and comforters into robes.

Tim Anderson

→ START

1. Make 3 cuts.

Make 3 cuts in the blanket as shown in Figure A (along the red lines). If you're going to add a hood and don't want a seam against the back of your neck, you can leave the triangular tab there. Otherwise cut it off.

2. Make 4 folds.

Fold the top parts of the blanket down to form the sleeves (Figure B).

Fold the sides in to form the body of the robe. Suddenly it looks like a robe!

3. Sew 4 seams.

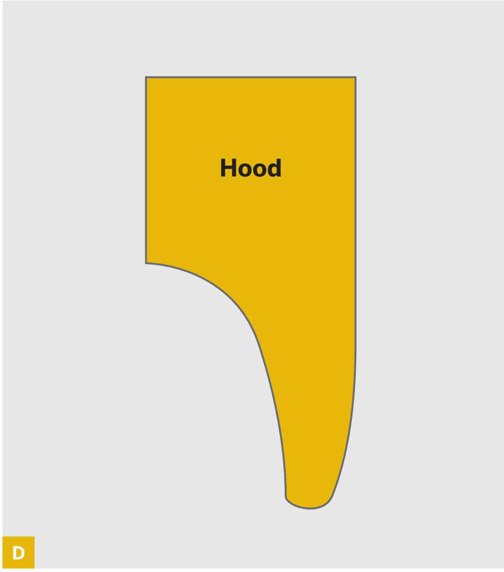
Sew the edges of the sleeves together along the line E–F and C–D (Figure C). Leave big enough holes for your hands!

Sew the seams on the front together, A to A and B to B.

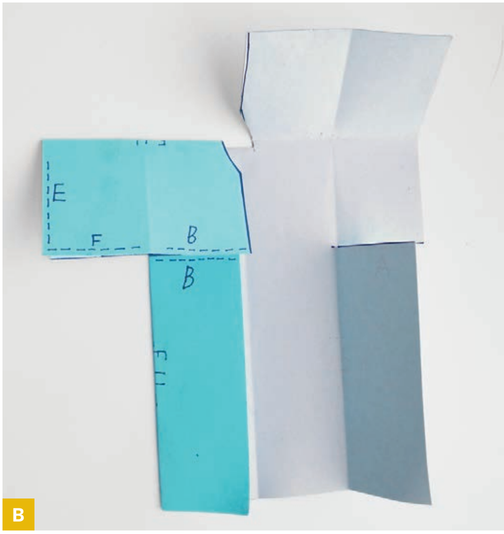
Don't sew under the armpits. Leave a gap there. Kimonos are like that as are the robes made by the Plains Indians — visit your local museum to see examples.

If your sewing machine has trouble with the material, get a thicker needle or sew it by hand. (Use really big stitches if you sew

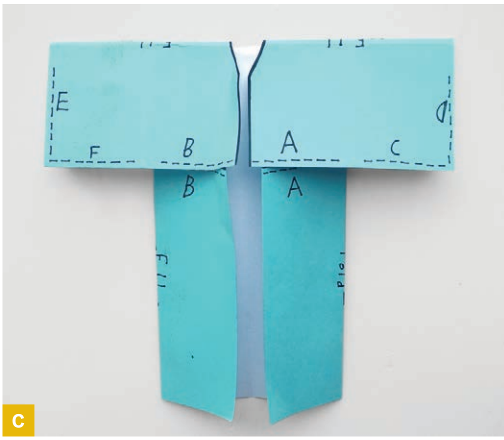
A



D



B



C

it by hand so it's not so much work.)

There's not much left over. There were only a handful of scraps after making this robe, which ended up having a belt and hood made from the same material. This is an amazingly efficient use of cloth.

Run around giving everyone hugs in your new comfy robe!

4. Add a hood.

Cut 2 pieces that look like Figure D, sew them together, and then sew them onto the kimono to make a hood. Or cut a bigger piece and fold it over to save some sewing.

Get as carried away with details as you want. Add tassels to the hood, belts, pockets, double-breasted lapels with monkey skulls and sand dollars for buttons, etc.

To sleep in the robe, you can put your feet in one sleeve and tuck the other sleeve under your head as a pillow. Maximum coziness achieved again by this amazing traditional robe.

Tim Anderson (mit.edu/robot) is the co-founder of Z Corp. See a hundred more of his projects at instructables.com.

REMAKING HISTORY
By William Gurstelle, Workshop Warrior

The Tuning Fork

Build the 18th-century tool that replaced faulty pitch pipes.

AFTER MUCH OF THE CITY WAS destroyed by fire in 1666, London was elegantly rebuilt, and by the end of the 17th century it was perhaps the most prosperous city in Europe. Concomitant with that rebirth was a cultural revival that placed great emphasis on music.

Music, especially in the Baroque style, was everywhere, and many of England's most well-known composers, George Frideric Handel, Henry Purcell, and Jeremiah Clark among them, wrote and regularly performed in this period. One talented young trumpet player, John Shore, was feted by royalty and commoner alike. As his star ascended, he was named Sergeant Trumpeter to the English Crown, a lucrative position that allowed him to collect license fees from nearly every trumpet player in England.

By 1711, the multitalented Shore was a rich man who had a bit of leisure time. He decided to investigate alternatives to the pitch pipes that musicians of the time relied on to tune their instruments, which were often unreliable due to changes in temperature and humidity, especially in England's ever-changing climate.

Shore devised a new method for tuning instruments that he called the tuning fork. Impervious to weather, the metal fork provides the same clear, constant tone when struck, in all conditions. When he was asked to help tune an orchestra assembled for a concert, Shore would often say, "I have not about me a pitch pipe, but I have what will do as well to tune by — a pitch fork." He is said to have laughed heartily at his pun.

Although great care must be taken in dimensioning it, the wonderful thing about a tuning fork is that it's fairly simple to make. Given a small strip of aluminum or brass, fabricating a fork to strike a particular tone (Concert A, or 440Hz, the note that orchestras tune to, is particularly popular) can be accomplished with a few tools and a little elbow grease.

CLASSIC TUNE German-British composer George Frideric Handel's 18th-century tuning fork.

The Foundling Museum, London, UK / The Bridgeman Art Library

Calculating the pitch of a tuning fork is a function of its material composition and tine dimensions. The formulae are available in acoustical handbooks, but the equation gets complicated in a hurry because it has some higher-order terms and requires knowledge of several material properties, including the modulus of elasticity, density, and the moment of inertia for the shape of the tines.

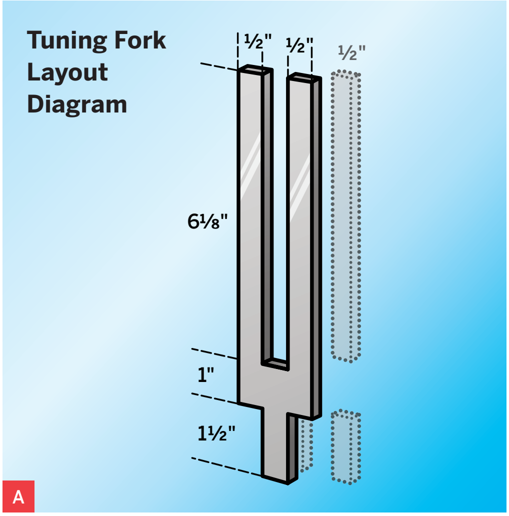
Here's how to make a fork close to Concert A that can be fine-tuned by listening to the pitch and incrementally removing material from the ends of the tines.

MATERIALS AND TOOLS

Aluminum strip, ⅛"×1½"×9"
Wood boards, ½": 10"×5½" (4), 5 7⁄16"×4 7⁄16" (1)
Wood glue
Hacksaw
Flat file
Pencil
Ruler and straightedge
Drill and drill bits

→ START

1. Use a pencil to lay out cutting lines on your tuning fork. Tines ½" wide by about 6⅛" long will produce a sustained tone of 440Hz (middle A on the piano). Mark the waste pieces with X's or other lines to be certain what to keep (Figure A).



A

2. Cut the aluminum bar to shape using the hacksaw (Figure B). This could take a while, depending on the keenness of your saw and the vigor with which you wield it.

Drill small holes in the end of the center waste piece so it can be removed (Figure C).


B

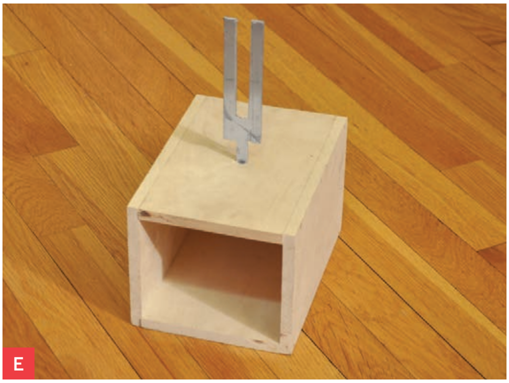

C

3. File the fork so the edges are smooth and even (Figure D). In order to obtain a clear, single tone, each tine must be dimensioned exactly the same. Likewise for frequency, both the thickness and length of each tine must be exactly correct. Checking against a pitch pipe or guitar tuner, carefully file the ends shorter until the frequency rises to exactly 440Hz.


D

4. To hear the tuning fork more clearly, mount it on a resonator box. Join the 4 long boards with glue to form a box with open sides. Let the glue dry (Figure E).

A resonator box works best when the length of the open box is ¼ the length of the tuning fork's wavelength. You can look up the frequency and wavelength of any note in an acoustical handbook, or online. The wavelength of Concert A (440Hz) is 30.9", so your box should be 7.7" deep to get the strongest tone. Position the short board 7.7" deep, adjust for sound, and glue it in place.


E

MAKE contributing editor William Gurstelle is the author of DIY books including *Backyard Ballistics* and *The Practical Pyromaniac*.

Damien Scogin (A); William Gurstelle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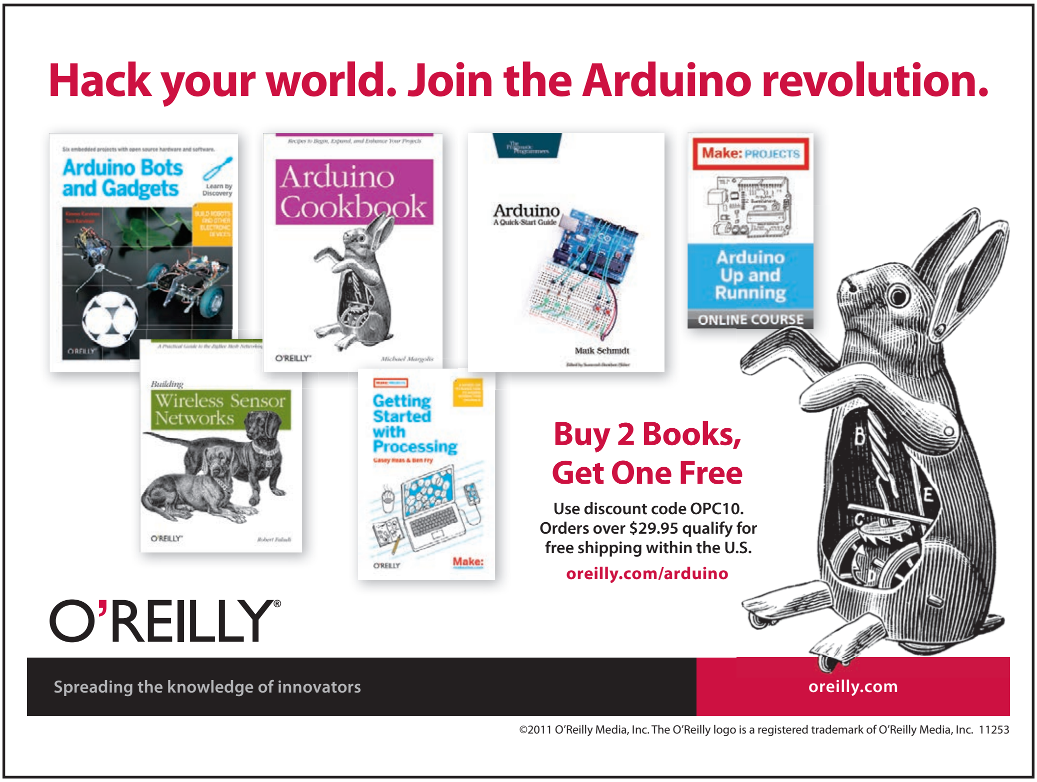
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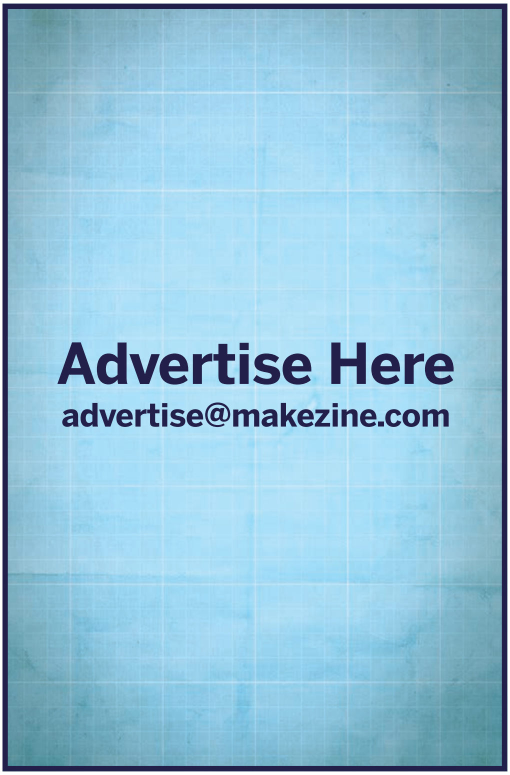
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HOMEBREW

My Arduino-Equipped Still

By Jay Settle

Jay Settle

AT CORSAIR ARTISAN DISTILLERY IN Nashville, where I work, we came across a 1920s copper still that escaped Prohibition, and we were dying to put it to good use. Unfortunately, it was missing the crucial piece that allows us to view temperature readings, which reveal everything about the distillation process from beginning to end. In addition, we've got a bit of a time pinch when the liquid begins to foam — we have to cut the heat within 10 seconds so it doesn't boil over into the batch. Foam-over in a still run is catastrophic!

To prevent it, distillers either use a silicon anti-foaming agent (yuck), or, like us, they use their eyes to visually monitor it through a sight glass and then adjust the heat accordingly. During each distillation, we wait for the foam to pass by the sight glass, and then cut the heat to let the mash settle. After 5 minutes, we turn the heat back on at a lower setting and let it roll for the remainder of the distillation.

When you want a monotonous task to just work itself out, day after day, learn Arduino. Recently, I had messed around with Arduino to turn things on and off, and I knew I could wire up a couple of temperature sensors and view the still's temperature on an LCD screen.

I found a photoresistor that could measure light, wired it into the microcontroller, and placed it over the sight glass. There's a significant light shift when the light reflects off the foam. I wired a 12V motor to the still to control the heat, and a water on/off valve to control water flow to the condenser. This way, the Arduino could have a "digital eye" into the sight glass, watching relentlessly for the foam and controlling the heat accordingly.

I spent some time perfecting the code, and now we pump in the liquid, flip a switch, and walk away. The Arduino handles the rest.

Jay Settle's passion for automation with Arduino is documented at makezine.com/go/jaysettle.

Sean Martin uses ShopBot to customize Olympic snowboards on the fly

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WHAT'S NEW *"We're working intensively with Thedo Remelink, the coach for the Steamboat Springs team, to develop a more competitive race board line. We are serious about getting Donek riders up on the Olympic podium!"*

Donek is a Colorado-based snowboard and ski maker that's been handcrafting some of the best snowboards and skis in the world since 1987, when its founder Sean Martin was still in high school. Sean has combined his skills in engineering with passion for sport to run a business that has been growing non-stop. Sean's innovative designs, attention to detail and exacting standards have earned him honored status among riders everywhere, including Olympian Zoe Gillings, who competed in the 2006 Turin Games and 2010 Vancouver Games riding Donek boards.

Sean builds each board with the help of a full-size ShopBot he bought in 1999. Sean says, "I needed CNC technology to be able to customize the boards and produce them efficiently. I wrote software that allows me to change the parameters and shapes of a board with just a couple of keystrokes."

Sean's ShopBot takes a lickin' but it keeps on tickin.' He says, "My original ShopBot has been hard at work 6 hours a day, 4 days a week -- for the past eleven years!" He just purchased a second ShopBot to keep up with demand.

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