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» OPERATE A CAMERA REMOTELY

» TV-B-GONE HOODIE: TURN OFF A TV WITH THE TUG OF A ZIPPER

J.D. Warren and his Lawnbot400

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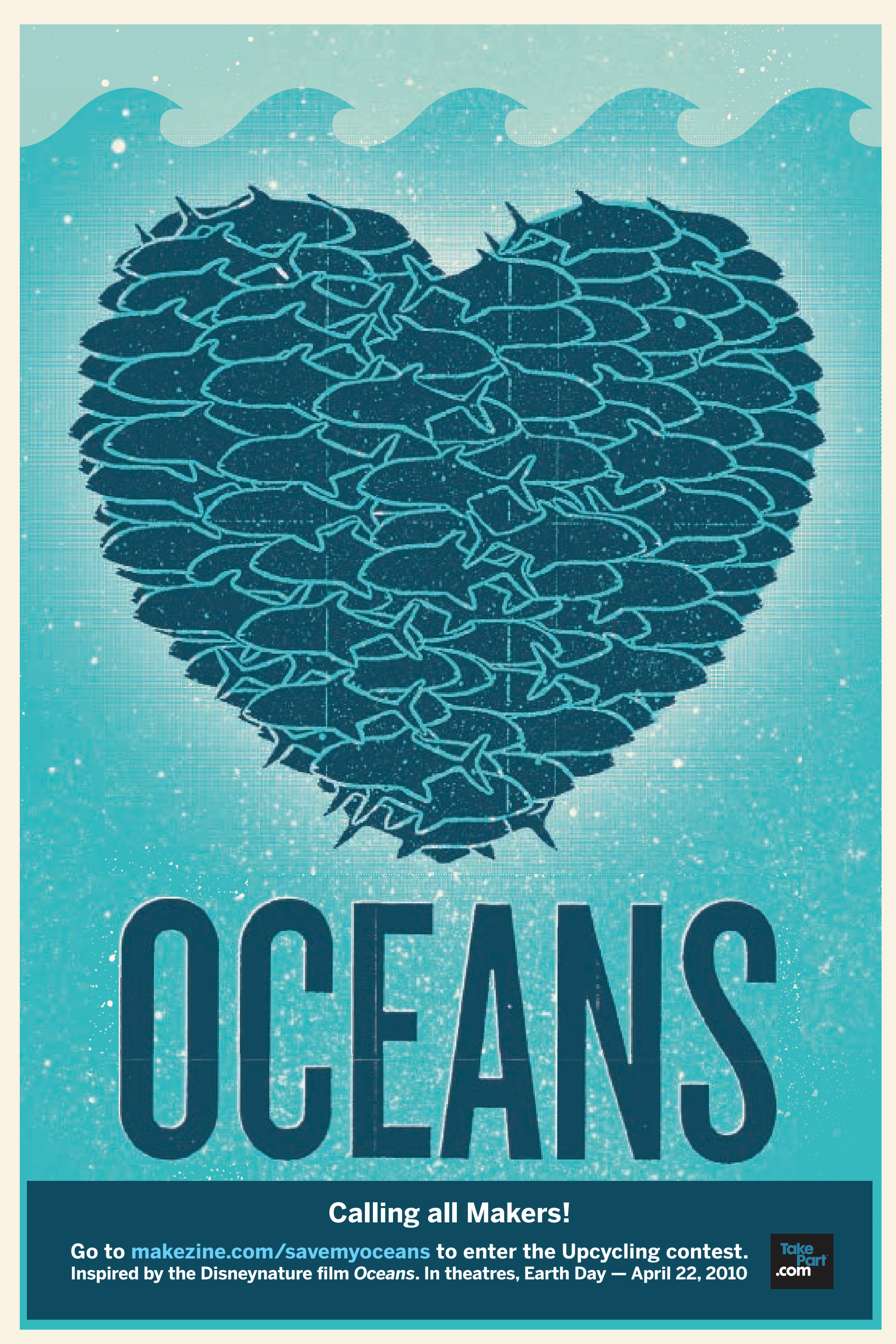
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BY MARK FRAUENFELDER

Open, Sesame

In September 2008 I got a phone call from my post office in Los Angeles. They told me a package addressed to me was making high-pitched noises. They wanted me to come get it immediately. I was in Illinois on business, but I called my wife and she went in to pick up the package. Inside were six Plymouth Rock chicks, which we'd ordered online from My Pet Chicken (mypetchicken.com).

Before I left for Illinois, I'd prepared a large cardboard box by lining it with sawdust and adding a feeder, a waterer, and an infrared light for warmth. My wife and kids took good care of the chicks, and when I returned a few days later the birds had already grown compared to the photos my wife had emailed me.

In six weeks the chicks were big enough to move to a proper henhouse outside. I wanted them to be able to scratch and roam around our yard in the day, and sleep in the henhouse at night, safe from the raccoons, skunks, owls, hawks, bobcats, and coyotes that live in our neighborhood.

The problem was that my chickens are early risers and I'm not. They scolded me whenever I let them out after 7 a.m.

After a few weeks of waking to the alarm clock, I went online to find a motorized chicken door opener with a timer. There were a few, but I didn't like any of the commercial products, because for one reason or another they didn't meet my needs, or they just didn't seem very good.

Then I stumbled across an automated chicken door invented by John Beaty, the director of technology programs at Northeastern University in Boston. His door (see it here: makezine.com/go/beatycoop) used a motorized drapery puller, the kind used by home automation enthusiasts. The beauty of the drapery puller is that when current is applied to it, it turns its motor in one direction, and when current is applied again, the motor reverses direction.

Beaty's door slid up and down, connected by a cord to the drapery puller, which was plugged into an ordinary appliance timer switch. When the timer turned the power on (once in the morning and again at night), the motor's pulley would draw the cord attached to the chicken door up or down.

> You'll learn how to make a remote control lawn mower, hack remote control power outlets, cheaply control appliances over the web, and drive a toy car with "telekinesis."

This looked perfect. I ordered the drapery puller and followed Beaty's description to build an automated chicken door of my own. I was very happy with the results (here's a video: vimeo.com/4177373). A few months later MAKE managing editor Shawn Connally and her husband made one for their chicken coop.

Automatically or remotely controlling tasks is the theme of this issue. An automated chicken door is just one of many cool features in Alan Graham's high-tech henhouse on page 64, which he controls via his computer or iPhone, so that his chickens are always warm, well-fed, and safe at night.

You'll also learn how to make a remote control lawn mower, hack remote control power outlets, cheaply control appliances over the web, turn off TVs with a sweatshirt zipper, and drive a toy car with "telekinesis" (there's a trick involved, but it's neat anyway). As usual, the magazine is loaded with lots of other projects you can make and use.

By the way, I've got a new book out about my experiences with raising chickens and bees, building cigar box guitars, growing vegetables, and other DIY projects. Many of the people who regularly contribute to MAKE are featured. It's called *Made By Hand: Searching for Meaning in a Throwaway World* (Penguin), and it's available at your favorite bookstore or online at the Maker Shed (makershed.com).

Mark Frauenfelder is editor-in-chief of MAKE.

Make:

technology on your time

Make: REMOTE CONTROL

ON THE COVER: J.D. Warren's Lawnbot400 cuts the grass while he kicks back with a cool drink. Photograph by Robert Rausch, styled by Ronda LeBlanc. Greener grass provided by ForeverLawn (DuPont ForeverLawn Select VR).

MIND BOT: Control an R/C toy with this helmet.

Columns

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www.dyson.com

Other vacuums keep costing

Other machines are still designed to need replacement belts and filters – which can be tricky to find, let alone replace. Over five years the average maintenance cost could be $233.*

Dyson vacuums keep working

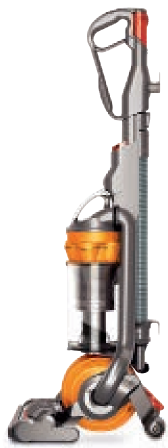
With Dyson there are no bags, filters or belts to buy. Dyson uprights and canisters are also guaranteed for five years so they don't cost a dime to maintain.

*Average five year maintenance cost of top eight selling upright vacuum cleaners by dollar sales (excluding Dyson vacuums) according to NPD data for 12 months ending October, 2009. Total maintenance cost over a five year period is based on recommended filter and belt replacement information provided by each manufacturer.

Dyson proves no loss of suction using the IEC 60312 Cl 2.9 test standard.

dyson

The vacuum that doesn't lose suction.



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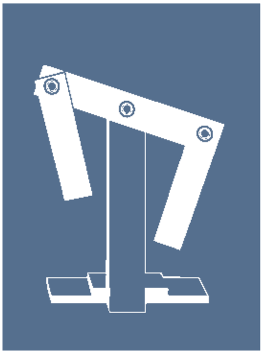

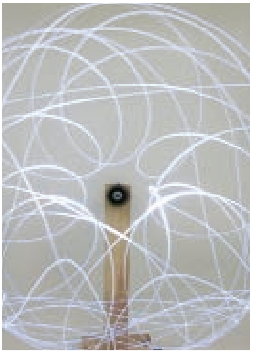

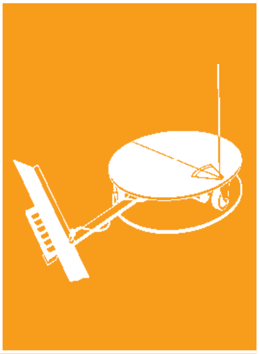

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Volume 22

Make:

technology on your time

Maker

INNER VISION: Brittny Badger's photos reveal the innards of appliances.

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

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"I have not failed. I've just found 10,000 ways that won't work."
—*Thomas Edison*

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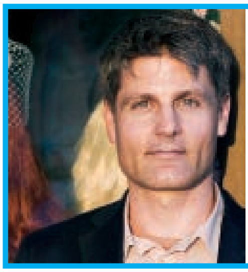
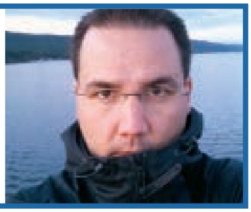


Robert Rausch (cover photography) is "addicted to triathlons" and lives on a farm in Alabama with his four kids, creeks, ponds, cats, dogs, chickens, cows, gardens, orchards, and bees ("I love my bees"). For his first photography job, he hand-colored his prints after finding out the client wanted color, not black and white. He's fond of the color blue (today), makes a mean gravy with biscuits, and is the artistic director for Serenbe, a sustainable living community. He has his fingers in many pies, whether art-directing books, teaching, photographing, building chicken coops, or designing textiles, logos, and light fixtures. His favorite tools are the pitchfork and the nail clipper, and he thinks this is a great time to be a designer.

Marc de Vinck (*Kitty Twitty*) is the Maker Shed product curator and a MAKE Technical Advisory Board member. He's worked as a traditional metalsmith, illustrator, and 3D model maker. Lately, his main interests include microcontrollers, interactive art, and anything using technology in a unique way. He also enjoys great design, in any medium. When he isn't building stuff — a rare occurrence — he can usually be found sailing with his family.

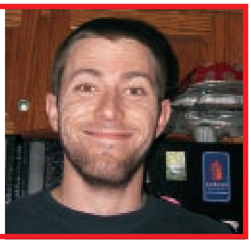


One String Willie (*Diddley Bow* and *Guitar Pickup*) is the stage persona of Philadelphia-area musician David Williams, who has played guitar in jug bands, old-time string bands, blues bands, and gospel groups for more than 45 years. A leader in the homemade music community and a recognized authority on the diddley bow, he's released two self-produced CDs of cigar box guitar and diddley bow music, *A Store-Bought Guitar Just Won't Do and You Gotta Hit the String Right (to Make the Music Swing)*, and appears in the cigar box guitar documentary *Songs Inside the Box*.

Born and raised in Santa Rosa, Calif., **Tyler Moskowite** (MAKE engineering intern) is a 22-year-old student in materials engineering at Santa Rosa Junior College. He has "a wonderful girlfriend Giulia, who is smarter than me, and the most amazing stray cat called Kitty." With a never-ending love for new technology and scientific advancements, he spends his spare time playing video games and learning to write code in Python and C/C++/C#. His current project is "programming an Arduino to allow an RFID card to unlock my car instead of the normal car key."

PES (*Boiling Spaghetti Without Water*) is an artist who has earned global recognition for his innovative short films and unique approach to stop-motion animation. Often working with familiar foods, household items, and found objects, PES has crafted some of the most memorable shorts of recent years, including *Roof Sex*, *KaBoom!*, *Game Over*, and *Western Spaghetti*, and directed dozens of commercials for brands worldwide, including Coinstar, PlayStation, Bacardi, Sneaux, Scrabble, and telecom giants Sprint and Orange. Perhaps director Michel Gondry said it best: "Clicking on a PES film is to open a safe and suddenly see a million ideas glittering and exploding. The only reason you close the door is to reopen it just after and discover what will pop this time." eatpes.com

John-David Warren (*Lawnbot400*) is a 27-year-old maker from Pinson, Ala. He loves the outdoors and spending time with his wife, Melissa, and their three kitties, but he's also a computer geek who loves tinkering with electronics at his workbench. A devout Christian, he believes he has "the ultimate Maker" behind him as he works. He is currently adding improvements to his R/C lawn mower and has a few other prototype bots in the making, but has recently "become consumed with designing and etching my own PCBs." He loves the idea of automating everyday tasks like feeding pets, watering plants, mowing the lawn, and even unlocking the front door. His favorite tool is "by far" the cordless drill.



BY CORY DOCTOROW

Are You the Scanner or the Barcode?

On a recent trip to Walt Disney World, I played the excellent new *Kim Possible* mobile game in Epcot where players are loaned a special cellular phone with various sensors and emitters in it. The phone plays videos about mysteries taking place in Epcot, which players solve by visiting sites and waving their phones at props that animate when they sense the proximity of the device, using the phones' geolocation and readings from the phones' RFIDs.

It's a very clever game: not only does it bring some much-needed tween entertainment to Epcot's World Showcase, but it also does some insanely clever networking stuff, spreading players out by sending them after clues in less-crowded parks based on up-to-the-second information about loading.

But it got me thinking: why is the phone emitting and the world sensing? Why not build the sensors into the phone and the emitters into the world?

This question is at the center of any number of thorny policy questions about privacy, surveillance, freedom, and open systems. The last decade has seen an enormous growth of sensors and readers, from the RFID toll-payment system glued to your windshield to the two or even three cameras in your mobile phone to the CCTV your nosy neighbor is using to spy on your backyard pool. The possibilities for emitting and sensing data are genuinely revolutionary, and many of us in the computers, freedom, and privacy crowd have been worrying that privacy's headed for the guillotine.

The problem is that this stuff is both cheap and cool, and there are a million things you can do with it that make the world seem like magic — the contactless cards that let you gas up, get on the bus, or get into your building by waving your wallet at some reader, for example.

Since sensors are more expensive than emitters, all the early effort was on developing applications that assumed emitters would be stuck all over you so that the relatively sparse sensors in the world around you could figure out where you were and adjust accordingly. You're the barcode, and you wave yourself at various checkout points to activate them.

But sensor prices are crashing. My latest phone, a Google/HTC Nexus One, has an extra mic solely for noise cancellation; last year I was carrying around a Nokia phone with two cameras, one outside for snapping the world and one inside for videoconferencing. Magstripe cards can increasingly be swiped in any direction — the readers have two, or even four, reading heads. This year's CES coverage suggests that 2010 might well be The Year They Put a CCD on Everything (including my dentist's new X-ray machine, which no longer uses film).

> Why is the phone emitting and the world sensing? Why not build the sensors into the phone and the emitters into the world?

Which presents the potential for a very disruptive future: one in which you are the register and the world is barcoded. That's what the Semacode people have been working on forever; it's what drives mobile apps that scan UPCs on store shelves and tell you where to go for cheaper stuff, but that's just the start of things.

Thus far, RFIDs in products have been designed with stores, not customers, in mind. It needn't be so. And even where there's no UPC or RFID or other identifier, devices with high-resolution cameras and geolocative sensors have lots of options for figuring out more information about their environments: reading and parsing model numbers, part numbers, and street signs with optical character recognition and database lookups.

It all depends on how the system is designed, and why. A networked society that treats people as scanners and keeps their data on their devices or in their encrypted private networked storage is one in which we can navigate the world better. One that treats humans as objects to be scanned, managed, and regimented is one that realizes the worst technophobic nightmares.

The choice is ours.

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.

BY GARETH BRANWYN

Make a Connection and Share Your Story Online

This year at Make: Online we're focusing on connecting the amazing people who make up the growing community of MAKE readers and visitors to our websites. We're revamping community-related services on the sites, adding more participatory features, and generally making a more inviting place to not only read about making, but also share your own projects, connect with fellow makers, and feel good about "learning out loud."

Here's a little checklist of things you can do to get more involved with the maker community online.

☑ **Register on the site.** To encourage thoughtful, open sharing of ideas and questions, and create a more welcoming environment for exploration and learning, we've written new Community Guidelines and instituted a "be nice" commenting policy, on both Make: Online and CRAFT. View our guidelines and register for your user account at makezine.com/comments and craftzine.com/comments.

☑ **Join the MAKE Forums.** Our new community manager, Matt Mets, is moderating our MAKE Forums area. The forums are a great place to discuss projects you're working on, ask technical questions, share your expertise, and discuss any and all aspects of making. Join in at forums.makezine.com. CRAFT has active forums, too, at forums.craftzine.com.

☑ **Post to the Maker Events Calendar.** We're spending more time marking up our events calendars with awesome DIY happenings around the country and the world. We do weekly calendar roundups on both the MAKE and CRAFT sites. If you know of any events, post them to makezine.com/events and craftzine.com/events.

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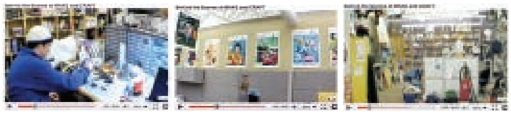
☑ **Submit your projects.** We're always on the lookout for great content, to post to the websites and to run in the magazine. If you have a project we should take a look at, just use our Suggest a Site forms at makezine.com/go/suggestmake and craftzine.com/go/suggestcraft.

This Week in Maker Events



☑ **Get your group in our Community Directory.** Want to connect with makers near you? We're building an astonishing directory of Make: City groups, hackerspaces, Dorkbots, TechShops, and other making/DIY groups — makers really are everywhere! Check it out at makezine.com/groups, and to submit your group, email mattm@makezine.com.

☑ **Run a Mini Maker Faire or start a Make: City group.** Imagine how cool it would be to run a Mini Maker Faire in your town. To learn how, check out diy.makerfaire.com. And if you're interested in starting a local MAKE group, email mattm@makezine.com for more details.

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BY SAUL GRIFFITH

Celebrate the Machinery

At the moment, the thing that's exciting me more than anything else is a tricycle. I know that probably doesn't sound like a big idea, or even cool in any way. Tricycles are for kids at best, right? Well, makers get involved in all sorts of projects and follies for reasons we probably can't explain to our spouses, and sometimes can't even explain to ourselves.

But this time it's a little different; I can explain exactly why I'm building this thing and why I'm passionate about it. I'm trying to live an experiment right now, an experiment in living a climate-friendly life.

I know there are MAKE readers who don't believe in the science of climate change (some wrote me nasty emails last time I mentioned it), but I do believe in it, and I'm trying to do something about it.

I'm trying to go through the things in my life one by one and improve them or remove them, until I have a high-quality life that 7 billion other people could also live while avoiding the worst of climate change.

In order to accomplish that, one thing on my list is to build a cargo tricycle to get myself to work. But it needs to tilt around corners for stability, and it needs to go fast, faster than a normal bicycle. Faster even than those unfortunate souls who must battle city traffic in their cars? You bet — with an electric motor, this trike can do 20mph all the time, up any hill, anywhere.

But that's not why I'm writing this article. That was just my wordy preamble. You see, I like to imagine that really good design still has a place in the world. And if you want to make your projects beautiful to people other than yourself, you need good design. So I started thinking about how to make a new kind of electric hybrid tricycle with a lasting, attractive design.

I spend a lot of time in bike shops, to my wife's chagrin. (Though, to her credit, when we tried to think of fun things to do for my birthday recently, her first suggestion was, "Let's go to every bicycle store in the city, in one day.")

But bike stores aren't where the great design inspiration I wanted was to be found. Modern bikes are all kind of same-same, generic, the way modern cars all seem to be the same. Design is not dead, but sometimes it seems we're hell-bent on killing it — or at least burying it alive beneath a sleek, shiny surface.

So I was delighted to stumble across a funny little bar in the middle of San Francisco. I always like stumbling across little bars, but this one, Eddie Rickenbacker's, actually houses a collection of 20 or 30 early motorcycles.

What we might forget when we look at a modern Harley-Davidson is that motorcycles actually came from a heritage of motorized *bicycles*. I've often quipped to friends that the bicycle was to the 1890s what the internet was to the 1990s. There was huge design innovation and experimentation in all things bicycle, and then this weird thing called the internal combustion engine came along and the possibilities seemed boundless.

I found all the inspiration I needed at the intersection of the eras of the bicycle and the motorcycle. People didn't even know what to call these things yet! The 1911 Excelsior Auto-Cycle was one attempt to name the genre. The 1902 Peugeot Motobicyclette, the 1907 Indian Racer, the 1912 New Imperial Light Tourist, the 1915 Cleveland, the 1922 Motosacoche: these bikes hang from the walls and ceilings of Eddie Rickenbacker's, dripping with inspiration, gleaming with brass and chrome, all of them proudly showing off the new technology.

Every cam, every lever, every carburetor and belt drive was worn on the outside. These machines had nothing to hide; they celebrated new technology. There were no perfectly bland plastic housings, there was just sheet metal and castings and rivets. Why is it that on the cusp of the electric vehicle revolution, we feel the need to hide the interesting stuff? Why not show it off? I guess it's hard to make batteries beautiful and electric motors sexy, but that's the challenge I now have.

How do you capture the spirit and promise of a new technology and express it with delight in a new design? How do you exaggerate the coolness, not bury it in plastic? That's what I need to do with my tricycle. I've got to make you want and love the quirks, the oddness, to express the trike's freedoms visibly. In this case, freedom from carbon and foreign oil.

Saul Griffith is a new father and entrepreneur. otherlab.com


Let your geek shine.
Meet Jamie Robertson, SparkFun customer and 30-year embedded design veteran. When Jamie needed a small MP3 player that could respond smoothly to volume commands for his latest interactive art collaboration, he didn't head to the local electronics store. Rather, Jamie turned to SparkFun and custom built his own media device. After a few enhancements, his prototype became the MP3 Trigger – now available at SparkFun.com.
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©2010 SparkFun Electronics, Inc. All rights reserved. All other trademarks contained herein are the property of their respective owners. Read more about Jamie and his project with musician Mike Gordon and artist Marjorie Minkin at www.robertsonics.com, www.wmaastudios.org or www.makerjam.com.

THINGS I'VE LEARNED

BY TOM HECK

A Cabin from Scratch

In the spring of 1983, I was finishing up my second year at Virginia Tech. I still hadn't found a major that was right for me; I felt lost and frustrated.

While I was deciding what to do, I met a local guy named Eddie who must have sensed I was ready for a challenge because he asked if I wanted to build a cabin on his property. His offer caught me off guard since I had zero experience building. I thought about it for one night and decided this was exactly what I needed.

Eddie agreed to guide me in the building process. I started clearing the land about a month before exams started. After classes ended, I set up camp next to the building site and began to work from sunup to sundown. I moved in just three days before the fall semester. I lived in the cabin from summer 1983 to fall 1985. No rent. No utilities.

I built the cabin for $1,100 and the investment paid off in more ways than I could ever have imagined. The last time I visited the cabin was in 2000, and it was in good shape. I have no idea if it's still standing.

Some lessons I learned, in no particular order:

1. It's not critical to have electricity, running water, and a phone to be comfortable.

2. With no phone, it was hard for friends to contact me at the spur of the moment. With no phone, I learned how to plan better.

3. I learned how to conserve water. I learned the value of a clean and abundant water supply.

4. I learned to use a chainsaw without hurting myself.

5. I learned how to be quiet and enjoy it.

6. I learned that building a home is relatively easy — it's not rocket science. This knowledge has provided me with a great sense of security over the years.

7. I wished I had built a cabin with half the footprint and a second story. Building the foundation took an enormous amount of time compared to the rest of the building process.

8. As soon as I was done building the cabin, I found out about yurts. Had I known about yurts, I would have built one of those instead.

9. I learned how to become more self-sufficient.

10. I learned how to ask for help after I injured my back and needed help stacking firewood.

11. I learned how valuable electricity is.

12. I learned how to navigate a dirt road under all types of conditions (deep mud, ice, snow) and learned when to park and walk.

13. I learned how to stay warm in the winter. I learned how to cut wood and prepare kindling. I learned how to quickly start a fire in a woodstove and keep it going. I learned the value of a well-built woodstove.

14. I learned how to be super safe with fire. If my cabin had ever caught on fire, the whole thing would have burned down in minutes.

15. I learned how to play the banjo. My solitude and lack of distractions (like TV) afforded me lots of free time to explore and create. Even now, when I play the banjo, I'm reminded of all the hours I spent playing in the cabin.

Tom Heck is a daddy, banjoist, team builder, and maker. See photos of his cabin build at tomheck.com.

Illustration by Drew Morrison

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

MAKER'S CALENDAR

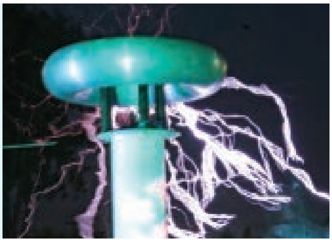
COMPILED BY WILLIAM GURSTELLE

Our favorite events from around the world.

Maker Faire Bay Area

May 22-23 San Mateo, Calif.

The world's largest do-it-yourself festival returns to the Bay Area, showcasing hundreds of extremely imaginative and accomplished makers. A two-day, family-friendly event filled with technology and craft-related performances, seminars, and exhibits. makerfaire.com



MAY

» Science Rendezvous

May 8, Toronto, Ontario

Science and technology organizations across Ontario open their doors to the public, offering free events and tours of the area's world-class research facilities, both academic and commercial. **www.sciencerendezvous.ca**

» Hamvention

May 14–16, Dayton, Ohio

Although it may sound like a giant meeting of bacon enthusiasts, Hamvention is the world's largest amateur radio gathering, with hundreds of exhibitors and forums. **hamvention.org**

» Windpower 2010

May 23–26, Dallas, Texas

Alt-energy buffs come together to discuss all things related to harnessing power from the wind. Includes an exhibition of product displays and a conference on both the technology and business of wind power. **windpowerexpo.org**

» Mutek International Festival

May 27–31, Montreal, Québec

Celebrate mutant technology at the largest of a series of international festivals exploring creative and playful applications of digital technology, focused on new electronic music and art. **mutek.org**

JUNE

» Rocky Mountain Star Stare

June 9–13, Pike National Forest, Colo.

The thin, clear air of the Rocky Mountains provides fields of stars by night, supplemented by day with astronomy workshops, children's activities, and amateur telescope making. **rmss.org**

» Vintage Computer Festival

June 19–20, Bletchley, England

The first-ever vintage computer festival in Great Britain comes to the National Museum of Computing. Activities include exhibitions of vintage computers, lectures, old-school computer music concerts, and a flea market. **vcf-gb.org**

» Glastonbury Festival

June 23–27, Pilton, England

The Glastonbury Festival is one of the largest cultural gatherings in the world. Besides music and dance, there are a host of maker-centric activities including green technology, crafts, and much more. **glastonburyfestivals.co.uk**

» Canadian Naval Centennial International Fleet Review

June 28–July 2, Halifax, Nova Scotia

More than 30 warships from over 15 countries will be open to the public for the Canadian Navy's 100th year. **www.navy.forces.gc.ca/centennial**

JULY

» Arlington Fly-In

July 7–11, Arlington, Wash.

Hundreds of pilots and home-made airplane builders descend on Arlington Airport to see and be seen in one of the nation's largest general aviation events. Activities include air shows, a car show, airplane building workshops, and more. **arlingtonflyin.org**

» Maker Faire Detroit

July 31–Aug. 1, Dearborn, Mich.

Motor City makers show off their technical and creative talents when Maker Faire Detroit comes to the Henry Ford Museum. The two-day, family-friendly event celebrates the industrial heartland's science and technology, engineering, food, and arts and crafts. **makerfaire.com**

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

MORE MAKER EVENTS:

Visit ***makezine.com/events*** *to find events near you, like new hackerspace classes, exhibitions, cool conventions, workshops, festivals, craft fairs, Make Clubs, Dorkbots, and more. Log in to add your own events, or email them to* ***events@makezine.com****. Attended one of these events? Talk about it at* ***forums.makezine.com.***

READER INPUT

DIY fabrication tools, the real world, and a mini wooden yacht.

Volume 21 is a very interesting read. I do have two quibbles. First, the warning regarding aluminum dust on page 91 ["Geared Candleholder"]. While OSHA has information regarding exposure to aluminum dust at osha.gov/SLTC/healthguidelines/aluminum, neither filing, drilling, nor sawing aluminum produce dust — they produce larger particles known as swarf. The warning is thus not applicable to the project.

Second, the "ESP Lamp" is a very interesting project, however I must object to the inclusion of what is little more than fantastical superstition. MAKE is fundamentally a magazine of science and engineering; there is no room for rubbish about "intent" and psychic phenomena. As can be attested by the current unclaimed status of the James Randi Educational Foundation's $1 million prize, and many years of study, there is no ESP or psychic effect to measure. When tests do show some small action, they are invariably plagued with flaws and poor controls. As the quality of study improves, the effect disappears.

Please leave psychic phenomena to the psychics. The real world is far more interesting.

—Paul Anderson, Mooretown, Ontario

Editor's reply: Thanks for the note, Paul. While Step 1's band-sawing and filing do create swarf, Step 5's sanding and polishing create hazardous dust. Erring on the side of safety, we ran the warning at Step 1.

With regard to the "ESP Lamp," the author also listed real-world uses for its truly random output, such as data encryption, neural networks, and statistical mechanics.

My son and I finally finished making the "Wooden Mini Yacht" [Volume 20]. We had a great time doing it. The rigging was a little challenging, and the grommets were difficult to put in, even with the Dritz tool. However, it all came together in the end. We look forward to sailing it.

—Jim & Max Castor, Redondo Beach, Calif.

Volume 21 is, in my opinion, the best issue of MAKE to date. I'm blown away by all the DIY fabrication tools now available to the small business or hobbyist. This issue reminded me of an article in Volume 03, "The Maker's Ultimate Tools" by Saul Griffith. Isn't it amazing how far we've come in less than five years? Volume 03 (2005) suggests a 3D printer for $25,000, a 3D scanner for $30,000, and a plasma cutter for $10,000! Jump forward five years and we've got the MakerBot for under $1,000, the DIY 3D Scanner for under $100, and an open source plasma cutter for around $1,000.

My son will be 8 years old in 2015. At this rate, he may have access to all of this technology in his classroom. If I have my way, he'll definitely have access to it at home.

—James Floyd Kelly, Atlanta, Ga.

Editor's note: One reason Volume 21 is so good is that it includes Kelly's "Your Own CNC for Less Than $800."

The only addendum I'd make to Forrest Mims III's terrific article on using a scanner for scientific applications is that it's a good precautionary step to use a sheet of clear acetate to protect the scanner glass. This is particularly good for samples like sand or soil, where the chances of scratching are high. I've found no loss of sharpness in my scans.

—Steve Salniker, Maryland Heights, Mo.

MAKE AMENDS

In MAKE Volume 20, there were two errors in the Auto-Phenakistoscope project. In Step 3d on page 106, the red wire should be soldered to the short leg of the IR sensor and the black wire should be soldered to the long leg. Also, the + and – signs were erroneously placed, as IR sensors do not have polarity.

In Volume 21, page 23, "The Art of Fusion" was not credited to the correct author, who is Annie Buckley.

In Volume 21 there's an error in the Reaction Timer schematic on page 105. Switch S5 should be connected to the negative wire, not to the positive wire.

Photography courtesy of Perugi Artecontemporanea

Cardboard Carbon Neutral

"Reuse" comes before "recycle" in the waste pyramid, and few people are as good at reusing as sculptor **Chris Gilmour**. His work, inspired by "a love of stuff," takes cardboard headed for the recycling plant and transforms it into a close look at the human obsession with objects as well as the psychology of waste.

His sculptures are the ultimate consumerist paradox: sturdy-looking cars, motorbikes, and scientific equipment made out of a relatively fragile material. They're about as carbon neutral as they come.

Gilmour started out using cardboard for prototypes, but soon realized its potential as a material: "It's very strong, you can make big things quickly, and it has a nice conceptual content: the idea of the object which was contained in the box disappearing and something new being created from the box," he explains.

Gilmour finds cardboard outside shops and morphs the former packaging into meticulous, life-sized re-creations of everyday items, whether a classic icon like a Fiat 500 coupe, a stovetop espresso machine, or a dentist's chair. Some of his works make use of the "patina" of color and text that come from old packing labels and tape.

His works-in-progress are as spellbinding as the final sculptures; each piece starts as sketches, photographs, and measurements, and is then built in jaw-dropping detail, cardboard skins sheathing cardboard skeletons. Bikes have delicate spokes, chains, and derailleurs; they're held up by spindly kickstands. A Lambretta scooter is enlivened by color from packing labels, its wiring and engine startlingly lifelike.

A Brit living in Udine, Italy, who also shows in New York, Gilmour has a unique perspective on waste: "In Italy, you tend to buy good quality and keep it for a long time. I think in New York, you buy it, use it, throw it away — I only need to think of the umbrellas they sell on the street on rainy days. They last precisely two hours, then break so you buy a new one. That said, there's plenty of waste in Italy, too, but that's good for me to pick up the materials."

—Arwen O'Reilly Griffith

Gilmour's Gallery: chrisgilmour.com/en.opere.html

Photograph by Michihiko Goto

Rocking on Eggshells

Scrambled, poached, or sunny side up? How about in stereo? **Michihiko Goto** (who goes by **Gomhi**) of Hamamatsu City in Shizuoka, Japan, carved these mini speakers from the classic breakfast staple: eggs.

Inspired by an image on the cover of the Fostex Company's *Craft Hand Book: Speaker Craft Manual Vol. 1*, showing what appeared to be an electronic egg sounding off, Goto, 33, decided to make a set of his very own.

First, he emptied store-bought hen eggs by drilling a small hole in the shells and letting the goo pour out. Next, he cut the shells with a mini router and chiseled the speaker drivers' plastic frames with a nipper before nestling one driver — a HiVi B1S transducer that converts an electrical signal to sound — into each egg.

To ensure the driver arms didn't break their housings, he lined the back of each shell with cotton and used acrylic foam tape on the front. Each speaker rests atop an air-dry clay foot.

"Eggshell is harder than I expected," Goto says. "For me, to mark the cutting line precisely on the eggshell is the most difficult thing. I heard there is a good tool known as Egg Marker."

He wasn't in it for the chicks. Although Goto describes the sound that comes from the speakers as "narrow," he says, "Surprisingly, my wife almost took the sound from eggshell speakers for our favorite in everyday use."

The music that sounds best through the eggs? According to Goto, it's *Water Strings* by Masako Toda, because of the female vocal and acoustic guitar.

Since he made the eggshell model, Goto has considered turning his wife's pottery, pieces of bamboo, even calabash gourds into speakers. But his wife specializes in *urushi*, Japanese lacquer used for traditional arts and crafts, and Goto says that'll definitely be his next medium.

—*Megan Mansell Williams*

Gomhi's Blog (Japanese): uziinoh.blog.so-net.ne.jp

Photograph by William Gurstelle

Trebuchet Tossables

It's an ethereal sound, Doppler-like and downright spooky. "It scared us the first time we heard it coming at us," says **Kurt Modert**, from whose Minnesota backyard the sound emanates. "Who would have thought a bowling ball could make such a sound?"

Modert, with his friends **Roger A. Bacon**, **Ryan Krueger**, and **David Proehl**, built an enormous trebuchet on Modert's exurban St. Paul property. Enormous even by medieval standards, their catapult is large enough to throw heavy objects 700 feet into a grassy field, now well-pitted and cratered from hundreds of high-impact landings.

The builders are skilled scroungers, picking up most of the building materials at a fraction of the retail price. They made the trebuchet frame mostly from scavenged lumber. The swinging counterweight, the key to any good siege engine, is a 265-gallon oil tank they got for free off Craigslist and filled with sand.

Still, their investment is at about $3,000 and growing, much of that going for expensive hardware and fasteners. But the cost is minor compared to the joy they get when they hurl stuff.

Projectiles to date have included a variety of non-working items: television sets, microwave ovens, bicycles, a wheelchair, a ladder, and several gas grills.

According to the four builders, the best "tossables" are bowling balls. A full rack of multicolored bowling balls sits in a nearby shed. Their favorite ball is nicknamed The Howler.

The Howler is a green 13½-pounder, once used in a bowling alley pro shop to help bowlers find the best place to drill finger holes in customized balls. So it's got a lot of holes. When launched, the spinning ball careers through air, the aerodynamics of the holes producing a loud, human-like wail that pretty much freaks out everyone who hears it.

Modert's nearest neighbor is several hundred feet away. That's probably a good thing.

—William Gurstelle

Trebuchet Group: makezine.com/go/fbtrebuchet

Network Tormentations

Austrian-born artist **Gordan Savicic** subjects himself to some tight restrictions for the sake of discovery. The Netherlands resident is creator of *Constraint City*, a fetish-inspired piece that explores the realm between public and private space.

Savicic, 29, began crafting tactile objects and media installations while studying digital art at Vienna's University of Applied Arts in the early 2000s. Still, he says, he's far from a traditional designer. "Most of my works require a spatial experience, where various concepts of interactivity are questioned and reflected," he explains.

That's the case with *Constraint City: The Pain of Everyday Life*, a corset-like piece designed for wear while walking in heavily wi-fied areas. Its straps are made from recycled seatbelts and controlled by three high-tech servomotors, a Nintendo DS Lite with interface cartridge, and custom-written software that constantly scans for encrypted wireless networks.

Real-time data operates the motors, which tighten the straps up to 9cm, depending on an encountered network's signal strength. A GPS receiver records each network onto a memory card, resulting in a map of wi-fi "torture" zones.

The idea for *Constraint City* stemmed from necessity. "In 2006 I didn't have a stable internet connection," says Savicic, "so I was riding my bike with a laptop in my arms [trying] to find an unencrypted network to send emails."

He'd also been reading Michel de Certeau's *The Practice of Everyday Life*, which sparked an interest in comparing basic city structures with a CPU circuit. "My aim was to literally experience the urge for connectivity within an altered city exploration."

Savicic's initial *Constraint City* cartographic performance took place in Vienna in 2007, lasting two hours and resulting in ample bruising. It was also on display at ISEA2009 in Dublin.

"I have no tendencies toward masochism," he says, "[so] it turns into a kind of 'real game' where you have to elude popular wi-fi areas."

—*Laura Kiniry*

» ***Constraint City*** **Pictures and Video:** pain.yugo.at

Photograph by Margarete Jahrmann

Photograph by David Battino, storycardtheater.com

Manga on Wheels (with Snacks)

Creativity soars when the economy crashes, and during the Great Depression in 1930, a Japanese street performer hit on a brilliant idea: he drew up a stack of large, colorful cards to enhance his storytelling — one card per scene. This *kamishibai* (paper theater) proved so popular that within a year, there were 2,000 kamishibai men in Tokyo alone.

Operating from bicycle-mounted stages, they sold crackers and candy to their audiences before starting the stories; whoever bought snacks got to stand closest. By the 1950s, it's estimated there were 50,000 kamishibai men in Japan, entertaining 5 million children a day. But then TV arrived, and the street performers disappeared almost overnight.

Last summer, my wife and I toured with **Tameharu Nagata**, 82, one of the last surviving kamishibai men in Tokyo. Nagata, who stands about 4-foot-11, rides a bike that weighs 100 pounds with the kamishibai stage installed. It has two drawers filled with rice crackers, gooey candy, and his wife Yoshi's homemade pickles, plus a flip-up frame for the story cards.

Nagata sets up on street corners, sells snacks, and tells a story called "Tetsu no Tsume" ("Claws of Steel"), a cliffhanger featuring an Asian Superman/James Bond character. (It's easy to see how the colorful, paneled graphics of kamishibai directly influenced manga comics.)

Performing the story itself takes Nagata less than four minutes; the bulk of his time is spent selling snacks in inventive ways — quizzes, contests, and skill tests, such as breaking a brittle pink wafer into more than ten pieces with a single blow. The kids love it.

"Once in a while, thinking about my age, I say that I should quit," he confides. "But every time I say that, kids come to our door to tell me to continue. I don't want to disappoint them, so I decided to keep on performing until I really cannot ride a bicycle. It's my life's work." *—David Battino*

Photos of Nagata-san's Bicycle Stage and Performance: storycardtheater.com/nagata

"Storytelling Man" Profile: makezine.com/go/nagata

Explosive Stuff

Like a magician of the everyday, **Felipe Barbosa** transforms common objects into unexpected works of art. Flattened soccer balls become an op-art masterpiece. Firecrackers turn a plush toy into a provocative sculpture.

Though crafted from mundane materials, Barbosa's work displays complex patterns and draws surprising connections between consumer culture, nostalgia, play, and aesthetics.

Born in the Brazilian city of Niterói, Barbosa attended art school in Rio de Janeiro, earning a master's degree in 2005. He lives and works in Santa Teresa, a historic neighborhood in Rio, and he mines supermarkets and *um e noventa e nove* (R$1.99) stores for raw material to make his delightful and idiosyncratic art.

Luckily for him, there's no shortage of stuff to take apart and put back together in a new way. For example, for his soccer ball pieces, "the models of balls change very fast, so I always have new and different colors and materials," he explains.

But it's more than just a vigorous supply that motivates Barbosa to make art out of plastic soda bottles and cheap neckties. He's interested in the way we associate thoughts and memories with everyday things, from green fields and orange slices to cuddling a favorite stuffed toy. The cultural and personal memories attached to objects add layers of meaning. "I don't change the nature of the object," he says. "I want to have it as raw as possible, so that what you know about the object becomes part of the understanding of the work I create."

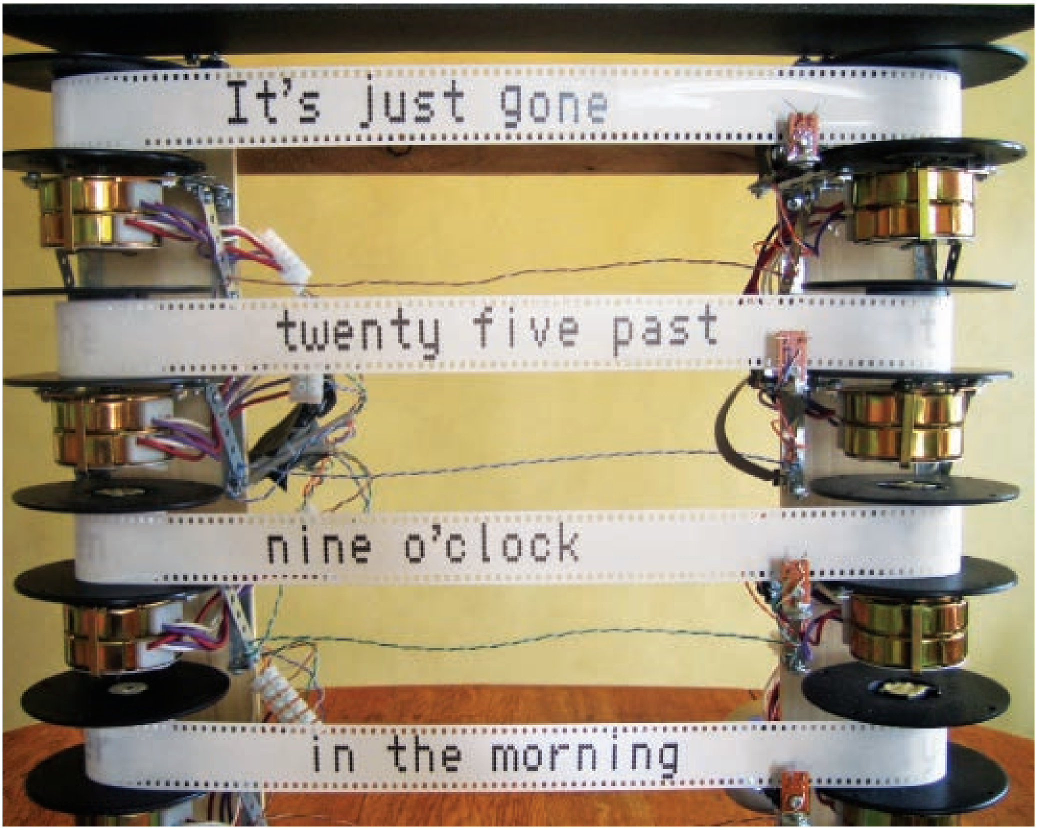
His newest works use "snaps" or firecrackers to make what are perhaps the least cuddly stuffed animals ever, though still very compelling.

Because viewers can relate to the materials, they don't need a background in contemporary art to enjoy the work. "Once I was showing a soccer ball piece in a gallery in Rio de Janeiro," Barbosa says, "and a guy appeared and started to kiss the work because I had a symbol of Flamengo (a very popular soccer team) on it." Now that's truly a love of art.

—*Annie Buckley*

>> **More Barbosa:** makezine.com/go/barbosa

Photograph courtesy of the artist and Sara Meltzer Gallery



A Reel-Time Clock

David Henshaw's Reel Time clock is about as far from "real-time" as you can get, but that's half the fun of this whimsical timekeeper.

One of a series of electronic clocks that Henshaw has built over the years, Reel Time tells time in pieced-together English sentences, displayed on rolls of 35mm film. Rather than displaying 6:05, the clock will inform you that "It's just gone five past six o'clock in the evening."

The clock's unique design incorporates a BASIC Stamp processor to control eight stepper motors, which rotate four separate reels of film. The project took six months of sporadic night and weekend work, and fits most definitions of a labor of love.

The most challenging aspect was getting the reels of film to rotate just the right amount so that the correct phrase scrolls into view, which required the number of motor rotations to vary depending on what time it was. After a couple weeks of debugging, Henshaw got the timing right and the Reel Time clock was off and running.

Henshaw grew up in Salford, England, but now lives in San Francisco, where the Reel Time clock was featured in an exhibition at the Mina Dresden Gallery last year.

Much of the clock is made with recycled and surplus components, including the bobbins, film, wood, and power supply, which were bought online or in secondhand shops. Henshaw also made use of Meccano metal construction toy pieces, Lazertran transfer paper, and military surplus motors.

If he could do anything over, it would be to build a better cabinet. As it is, whenever Henshaw has to move the clock, he says it feels like moving an antique.

Making things like the Reel Time clock is how Henshaw keeps the creative juices flowing while employed as an IT manager for a large financial institution. "Working on projects like this in my spare time is what keeps me sane!"

—Bruce Stewart

Reel Time Clock Build: dhenshaw.com/art/reeltime

Reel Time in Action: makezine.com/go/reeltime

Photograph by Morgan Renault

BY FORREST M. MIMS III

Data Mining: How to Analyze Online Scientific Data

The internet holds a treasure trove of scientific data. Never before has it been so easy for students, amateur scientists, retired professionals, and anyone with reasonable analytical and computing skills to do serious science. Even people without field or bench experience who have never used, much less built, an instrument can now make discoveries, possibly significant ones.

Data Resources

No matter what interests you most in science, you can probably find data that meets your interest somewhere on the web. Considerable online data is in the form of time series, collected at intervals ranging from seconds to years.

Here are a few sources:

» Tree ring data: www.ncdc.noaa.gov/paleo/treering.html
» Ozone layer: jwocky.gsfc.nasa.gov
» Weather (U.S.): ngdc.noaa.gov
» Sunspots: ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html
» Cosmic rays: ngdc.noaa.gov/stp/SOLAR/ftpcosmicrays.html
» Sea level change: sealevel.colorado.edu/results.php
» Stream flow (U.S.): waterdata.usgs.gov
» Satellite: begin your search at nasa.gov/about/sites

Software Tools

While a huge array of software is available for analyzing data and making charts, you can achieve much with a spreadsheet program. The latest version of Excel included with Microsoft's 64-bit compatible Office 2010 package is especially powerful. This program can handle millions of rows of data, a feature that is essential when analyzing particularly long time series of data. While Office 2010 is not free, you can download the beta version (microsoft.com) at no charge. Beta downloads will work until October 31, 2010, after which the program must be purchased.

An excellent alternative to commercial spreadsheet programs is Open Office (openoffice.org), a freeware package that includes Calc, a spreadsheet program with many of the features of Excel.

A Data Mining Example

Since Feb. 4, 1990, I've made near daily measurements of the ozone layer, total column water vapor, aerosol optical depth (a measure of haze), solar UV-B, and other atmospheric parameters from east of San Antonio, Texas. Now that this time series is 20 years long, I've become very interested in finding other long series of data from my area. The National Weather Service is one of many sites I've mined.

Formal temperature measurements at San Antonio began in 1885, and Figure A shows a chart of the average temperature for each year. The warming era of the 1930s, the present warming, and the intervening cooling are especially obvious.

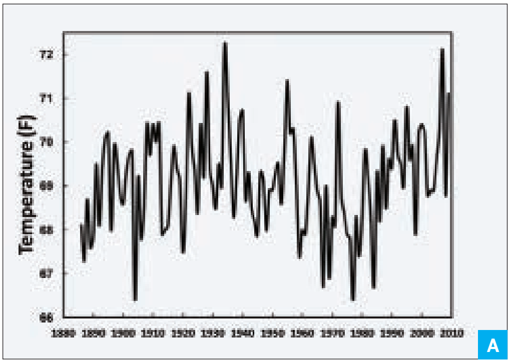
To make this chart, the data was saved as a text file and imported into Excel. The temperature data were given in degrees Fahrenheit, even though most countries and science publications use Celsius.

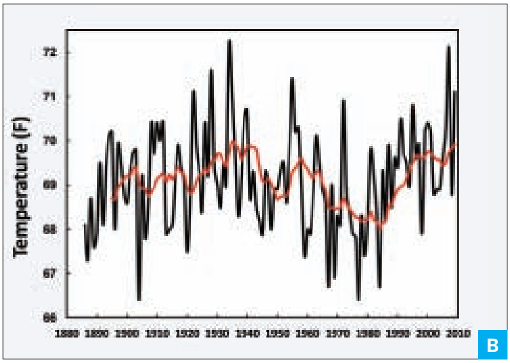
An advantage of the Fahrenheit scale is that it provides better resolution than the Celsius scale. You can easily convert Fahrenheit data to Celsius using the standard formula. The Excel version is `=(5/9)*(T-32)` where *T* is replaced by the column and row (e.g., P18) of the cell containing a temperature in Fahrenheit.

Figure B shows how the basic time series chart in Figure A can be embellished with a 10-year running average superimposed over the annual data. This addition serves to smooth the data and reveals patterns over time.

Figure C replaces the running average with a regression line that shows the linear trend of the entire data series. A line representing the mean of the data has been added so that the upward slope of the regression line can be easily visualized without cluttering the chart with grid lines.

Note the equation for the trend line in Figure C. This establishes the slope of the trend and allows you to determine how much the temperature has





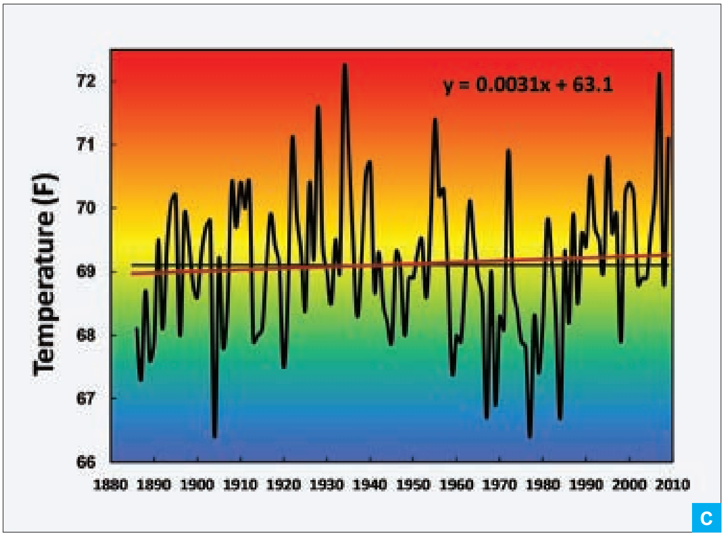


Fig. A: Preliminary annual temperature measured by the National Weather Service at San Antonio, Texas, from 1885 to 2009. Fig. B: Figure A with a superimposed 10-year running average that more clearly reveals patterns and trends in the data. Fig. C: Figure A with a superimposed mean and linear trend (given by the equation at top) and a color-coded background.

changed from the starting point to any year.

The regression equation is $y = 0.0031x + 63.1$, where y is the temperature (T) and x is the year. This formula gives $T = 68.94$ in 1885 and 69.33 in 2009 for an increase of 0.38 degrees.

Figure C is decorated with Excel's "gradient fill" option to provide a hot (red)/cold (blue) color-coded background for the chart. This looks good on the web and in general publications but would be inappropriate in a formal, peer-reviewed paper in scientific journals.

While it's common for climate scientists to plot linear trends of their data, this method misses significant fluctuations in the data.

For example, the trend lines in Figures B and C completely miss the warm temperatures of the 1930s and the cool temperatures of the 1970s. This and the uncertainty of many kinds of experimental data mean a linear trend line cannot always forecast changes to come.

Some Caveats

It's all too easy for statistics and pretty graphs to overshadow factors that might have influenced the outcome. For example, how reliable is the warming trend depicted in Figures A, B, and C? The NWS website for the San Antonio temperature data states, "Please note that these data are preliminary and have not undergone final QC [quality control] by NCDC [National Climatic Data Center]. Therefore, these data are subject to revision." This caveat is important for multiple reasons, since some NCDC adjustments to the climate record have been questioned.

Then there's the urban heat island effect. Based on a study at nearby New Braunfels, the urbanization of San Antonio has probably caused that city's temperature to rise several degrees since 1885. Thus, the increase of 0.4° F shown in Figures B and C would amount to a decline of several degrees in the nearby country. These caveats are amplified by the fact that the San Antonio weather station was

Illustrations and photograph by Forrest M. Mims III

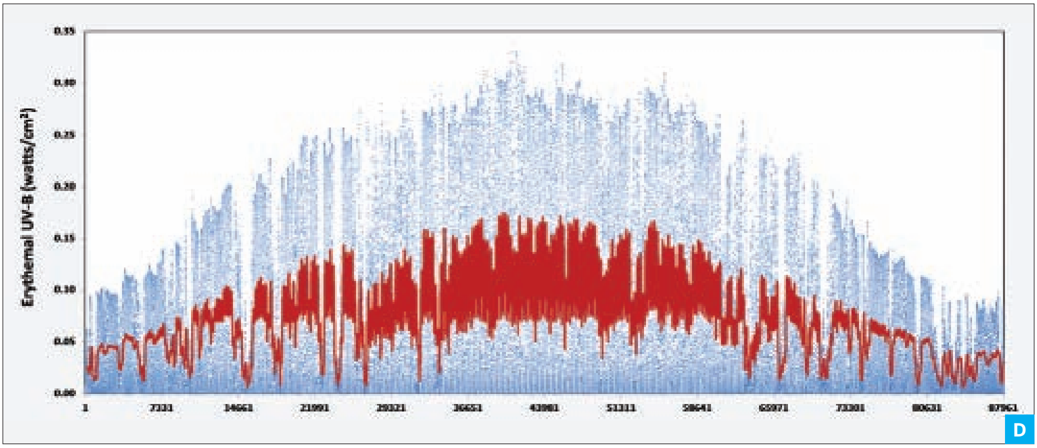


Fig. D: The 87,977 readings (blue) every three minutes and the seven-day running average (red) of solar ultraviolet radiation during 2009 measured by the USDA instrument in Figure E. Because of a few days of data outages, it wasn't possible to label the y-axis with dates. That's why I call this chart a "work in progress." Fig. E: UV-B data from this U.S. Department of Agriculture radiometer at Texas Lutheran University at Seguin, Texas, are online (see text).

moved several times since 1885.

Don't let these caveats discourage you. Just do your best to evaluate anything that might have affected the data you are studying. After all, even professionals face the same kinds of uncertainties.

Going Further

Figure E shows a solar ultraviolet-B radiometer on a rooftop at Texas Lutheran University in Seguin, Texas. This is part of a suite of U.S. Department of Agriculture sunlight instruments that I have managed for Colorado State University since 2004. It's one of more than 30 such instruments across the United States, and all the data are freely available at uvb.nrel.colostate.edu.

Figure D is a work in progress, a chart of 87,977 measurements of erythemal (sunburning) UV-B made by the radiometer in Figure D every three minutes during 2009. The feature in red is a one-week running mean of the data that clearly shows changes caused by the seasons and cloudy periods. This is one of many such charts I'm using to explore the data.

With patience and care, you, too, can make and analyze plots of data available online. But this doesn't mean you should rush your findings into print or onto the web. Posting or publishing research findings requires considerable care to avoid making mistakes and drawing the wrong conclusions. So be skeptical of your results and move forward with care. Learn basic statistics, explore your spreadsheet's functions, and find out how to add error bars to your charts.

If you're investigating an area of science that's new to you, be sure to seek advice from objective professionals. If you can demonstrate that you're serious about your research and want to do it properly, chances are they'll provide the advice you need.

If you do post or print mined data that you've analyzed, it's important to acknowledge those who collected the data and the website or publication where you found it. As a courtesy, you might want to first show your analysis to those who collected the data. They might be willing to check your work for errors and even establish a relationship for future collaborations.

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." He edits *The Citizen Scientist* (sas.org/tcs).

BY DAN WOODS

It's Alive! Makers Market Debuts

After a year of development, testing, fiddling, and designing, on Feb. 1 we took the wraps off Makers Market (makersmarket.com), a curated marketplace of wonderful science, tech, and artistic creations made and sold directly by some of our favorite makers from around the world.

A collaboration between MAKE and Boing Boing, Makers Market brings together our favorite entrepreneurial makers and artists selling products and services directly to DIY enthusiasts — people with a thirst for life-enriching exploration through hands-on science and tech projects, risk-taking, art, sustainability, self-reliance, and hands-on learning. And true to our character, we'll toss in a pinch of mischief-making for good measure.

Most of the sellers you'll discover in Makers Market are makers we've come to know through the course of our work producing MAKE magazine, boingboing.net, makezine.com, craftzine.com, Maker Faire, and *Make:* television.

Each maker was selected by the MAKE or Boing Boing crew and personally invited to open a storefront in the market. The products you'll find here were made by, rebuilt by, or substantially produced by the maker selling them. We call this Maker Made.

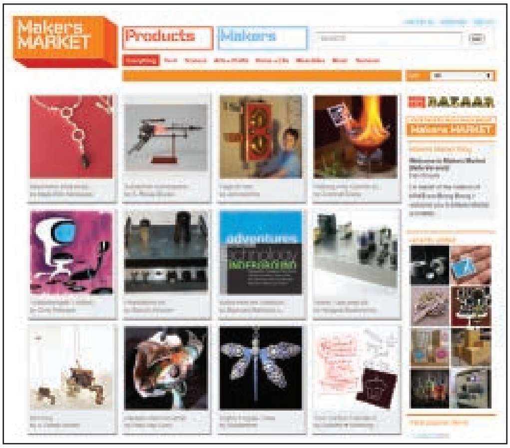
And each participating maker has his or her own Makers Market storefront, where they showcase their work and sell their products, write blogs, post pictures and videos, and communicate with their customers and the do-it-yourself (DIY) community at large.

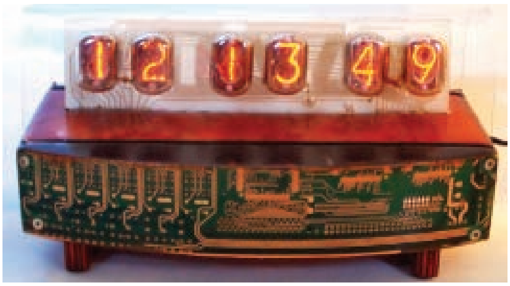
MAKE provides the web service, the tools, and the community. Sellers are responsible for doing their own product fulfillment and for bringing their unique character, energy, and DIY spirit to the marketplace.

I invite you to stop by makersmarket.com and check it out. If you're an indie maker with a product or service you think you'd like to sell in Makers Market, visit the Seller FAQs. Nominating yourself as a seller is easy and takes just a few minutes. We'll review your information and get back to you in a day or two.

For general inquires, feedback about the site, or just to get in touch with one of us about Makers Market, drop us a note at help@makersmarket.com.

On behalf of MAKE, Boing Boing, and the entire crew, thank you for your patience while we've been developing the site. We look forward to seeing you in the Makers Market.





Dan Woods is MAKE's associate publisher and Maker Shed general manager.

DUB AND DRONE: Tristan Shone performs as Author and Punisher surrounded by his handmade industrial sound machines.

Seriously Heavy Metal

Guitars are cool, but there's a whole other way to make heavy music.

Interview by Goli Mohammadi

Engineer and musician Tristan Shone conceives and machines instruments that look more at home in a factory than a rock venue and extrude deep, dark sounds rich with texture and emotion. We chatted with him about engineering versus art, the trials of fabrication, and industrial fetishes.

Goli Mohammadi: You started out as a one-man heavy metal band. Tell us how you transitioned to making your own instruments.

Tristan Shone: I had gotten rid of my previous band and went on my own, so I wrote sequence pieces that were basically for me playing guitar with all the bass and synth sequenced behind me. I would go and play live with that setup with a giant sound system, [but] it seemed like I needed to be more involved with the whole setup, like I needed to be basically in charge. It just felt kind of Milli Vanilli to me.

GM: How did you go from being a mechanical engineer to deciding to go to art school?

TS: I had been working for artists building installations while I was at RPI [Rensselaer Polytechnic Institute]. I met this guy Chris Csikszentmihályi, who is now at the MIT Media Lab. He was the art professor but he was very technically oriented — he knew how to program. He introduced me to microcontrollers, and he knew how to use CNC machines. He was also very interested in music, so I helped him with a couple of installations and traveled with him to a big festival. That kind of opened up this other world that was creative and technical yet kind of wacky, and the people were a little more fun to be around.

Photography by Glenna Jennings, Jeni Cheung (middle left)





GM: When you're creating an instrument, does the sound dictate the design or vice versa?
TS: The whole time I've made music I've been interested in this certain type of rhythm and a certain drone-y sound, and I'm always chasing it.

There's also certain elements of industry that I've come across that I really like, like when things snap-fit, or how there's a certain resistance you have on a wheel in a manual mill. It has a certain resistance that you can't really fake, so you have to actually make [the instrument] out of those materials. Sometimes I'll just feel one of these things and think, "That would be a great way to feel the sound and really have that natural force feedback."

Or something snaps and [I think], "That would be a really good drum sound if you had a lever that you move linearly and it just went *chnk chnk*." It's really simple — it's not dynamic like a violin, it's just like I'm moving this thing from there to there — but it's totally satisfying. I think it's the combination of the sound coupled with that industrial fetish.

GM: Your instruments require significant force from the performer. Does your experience playing them translate to the audience?
TS: With the older instruments [Drone Machines], you're really used to sweating. My favorite combination is [moving] the wheel [Rotary Encoder] with the right hand and the Linear Actuator with the left hand. And sometimes you have to stand on the table to really rotate [the wheel] and get it up to the pitch that you need. If it's spinning at full speed and then I have to stop it, it kind of torques my body to actually stop it. I think people see that and they appreciate it.

GM: What tools do you use to design?
TS: I'll sit and sketch and eventually come up with a general design in SolidWorks, which is like a look and a feel, and then start getting really detailed, figuring out if it's affordable, and how much of it can I make myself. And then from SolidWorks on to Mastercam for each part, if I'm gonna do it on a CNC. Some of the parts are on CNC and some are on a water jet.

GM: How do you choose your materials?
TS: There's a sculptor named Matt Hope, and he and I built some speakers together. He was a big proponent of stainless steel because it was a material that you don't have to paint, don't have to coat, it never rusts, and it's super strong, and so I bought into that because aluminum bends. But after building some stuff out of steel on the last machines, it's just not feasible to tour with. You cannot carry stainless steel stuff around.

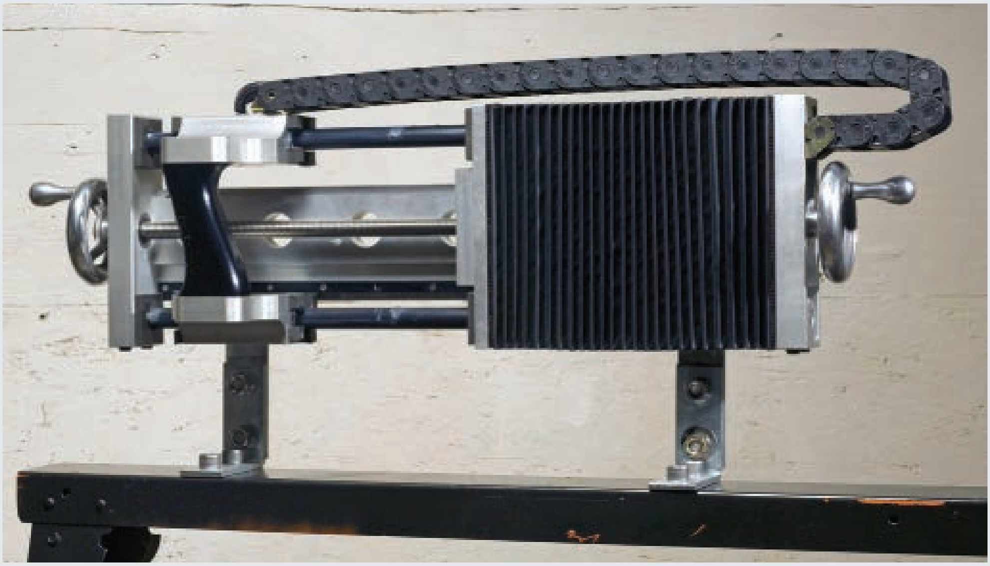
GM: How heavy are your instruments?
TS: The wheel is like 300 or 400 pounds. The first tour I went on, I went up to Portland, and my friend and I carried that up some stairs, along with all the speakers. When you first start playing, you're like, "No, I want to show everything." And as you go on, you're like, "Actually, I'm gonna start making things out of aluminum."

The newer devices are basically a reaction to traveling. I wanted to make smaller dynamic things that are within these limits. It's really nice to have limits like that. It's like, OK, I have a size restriction, I have a weight restriction. If you don't have any limits, it takes you forever — you can never make any decisions.

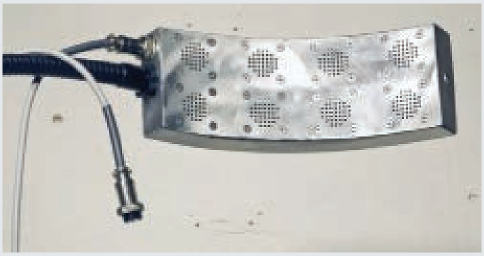
GM: What's going on in your laptop?
TS: Well, it's kind of sad, but everything. In my final [thesis] project, in front of all the professors, I kicked out the USB cable and it crashed my computer and I couldn't perform. I couldn't restart my computer and it was the most embarrassing thing. It was the first performance I ever did for the faculty. You have all this stuff and people expect it to do something and actually it's all communicating over the laptop.

They're essentially MIDI controllers — these things control software synthesizer sounds or samples. So like the Headgear, although I am using my voice through it, I can trigger whatever sample I want. And the wheel, I can record a whistle and control it with the wheel and that totally would work. It's just a serial command off the Arduino through the MIDI and then to Ableton or Reason or whatever, so without that there's no sound. I just decided at some point that I like electronic music. I'm not an acoustic person. I like drum and bass, and dub, and this is my world and those are the sounds I want to create.

+ Read the full interview and hear Author and Punisher: makezine.com/22/tristanshone



TURN IT UP: (Clockwise from top) The Rails manual rhythm controller; a close-up detail view of Rails; the Headgear octo-microphone USB/MIDI controller (learn how to make one on page 118); Shone in the studio playing the Headgear; the Rack & Pinion two-level, six-key sound controller with continuous pitch control for each key.



Learn how to make the Headgear on page 118.

Photography by Glenna Jennings

Pinball's Last Stand

How two legendary designers attempted to save the pinball industry by reinventing the game.

By Greg Maletic

George Gomez wasn't a fan of pinball, exactly; he was a fan of making things. An industrial designer by training, he'd spent the beginning of his career creating toys and coin-operated video games. (He was the guy behind Midway classics like *Tron* and *Spy Hunter*, and even had a hand in that cool *Gorf* joystick.)

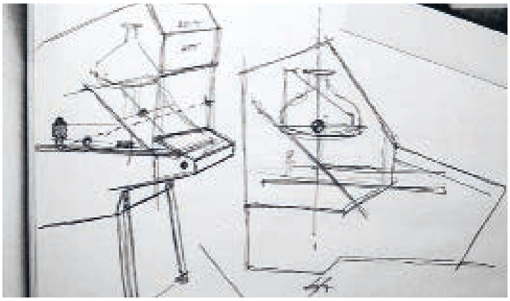
But, as Gomez says, "I'd always wanted to do a pinball machine. With conventional toys, you're working with an LED and a 9-volt battery, and you're working on something that has to cost $19.95. So here's this thing that costs $4,000, and there's range there to do some cool stuff."

Following his pinball dream, Gomez joined industry giant Williams, the company behind hit games like *Terminator 2* and *The Addams Family*. The year was 1993, and counter to those who thought *Pac-Man* and *Street Fighter* had killed pinball, the industry had just experienced its biggest boom in decades thanks to sales in Europe and novel technologies like dot-matrix score displays.

But by 1997, the novelty had worn off; so, too, had ever-more-complicated rule sets that alienated the casual pinball player. Kids were glued to PlayStation and Nintendo G4 home consoles. The pinball market was saturated. Complicating matters, the huge potential of Williams' new line of video slot machines left investors wondering why Williams was wasting its time on a product seemingly on its last legs.

CEO Neil Nicastro delivered an ultimatum: come up with a new kind of pinball machine so stunning as to make existing pin-games seem obsolete. The penalty for failure? Watch Williams' renowned pinball business close for good.

Photograph by Jim Schelberg, *Pingame Journal*



THE WIZARDS OF PINBALL: (Opposite, left to right) Pat Lawlor and George Gomez next to their hand-made Holo-Pin prototype. (This page, clockwise from top left) Early Holo-Pin sketches by Gomez; the prototype used an Amiga monitor and a half-silvered mirror to integrate video with pinball; and Gomez's ⅛-scale foamcore Holo-Pin model.

Photography by Greg Maletic (sketch, model), and Jim Schelberg

Desperate pinball employees churned out ideas, and the concept that emerged was one that replaced pinball's backglass with a 27-inch CRT that could show animation and video games to complement the pinball gameplay. The new platform — christened "Pinball 2000" — seemed promising. At least, it did to most people. But not to George Gomez.

Gomez worried that the concept would feel like substandard pinball welded to a substandard video game. "It didn't do justice to either format," he says. So he took his concerns to legendary Williams designer Pat Lawlor.

The solution, they thought, lay in the recent past, using a thing called a "combining mirror." Video games like *Space Invaders* and *Asteroids Deluxe* had used a half-silvered glass positioned at an angle to make a video image float in front of a painted cardboard background.

"The combining mirror trick was used in the early days to make video images appear more full than what the hardware was really capable of," says Lawlor. Applying this technique to pinball could let video images interact with the ball, something that felt like a quantum leap beyond the current plan's separate monitor and playfield.

Gomez and Lawlor shopped their idea around to co-workers, but no one got it. Nobody thought the image would be bright enough, or that the interaction between the ball and the video image would be satisfactory. Beyond the skepticism, the pinball group was resentful: by suggesting a change in direction mid-course, Gomez and Lawlor were effectively casting a vote of no confidence in the team's efforts to keep pinball afloat.

The two weren't deterred, but given the hostile environment at Williams, they knew they'd need to go somewhere else to develop their idea. While they spent their days at Williams, in the evenings they pursued their Pinball 2000 alternative in the more hospitable setting of Lawlor's garage.

Says Lawlor, "We could very quickly model, throw away, model, throw away, many iterations of what we were doing and not have a crowd asking for meetings, claiming failure."

Rough sketches led to an encouraging test with a ⅛-scale foamcore model. Next up was a full-scale prototype. "Pat had a pretty well-equipped place, but mostly we used simple shop and hand tools on that project: table saw, band saw, drill press," says Gomez.

PINBALL'S REVENGE: The playfield of *Revenge From Mars* (above), the first of two Pinball 2000 games; the Pinball 2000 cabinet (right) needed a larger backbox than traditional pinball in order to hold its video monitor in the proper orientation.

The bottom cabinet and playfield came from an old pinball machine Lawlor had at home, but the other, more novel parts of their prototype required some ingenuity. Video images were supplied by 2D artwork Gomez had stored on an old Amiga 1000, displayed on a salvaged 19-inch arcade monitor. To reflect the monitor image, the prototype needed a playfield glass that was semi-reflective. "We mirrored the glass with off-the-shelf limo window tint film from the local auto parts store," says Gomez.

After two months of hard work, they got their "eureka" moment when they saw an image — in this case, a bitmapped illustration of a robot — seemingly standing on the pinball playfield. Says Gomez, "I still remember the excitement when I realized that it was really going to work."

Their prototype was still crude — the game's static video images didn't interact with the ball — but there wasn't time to take the idea further. The original Pinball 2000 concept was advancing, and Gomez and Lawlor got the hint that it was now or never for their alternative.

They packed up their "Holo-Pin" prototype and headed back to Williams to unveil it to management and engineering teams. The anticipated reaction?

"I had no idea," says Lawlor. He and Gomez had already flatly rejected the concept their co-workers were now throwing all their effort behind. "Politically, what we were doing was very upsetting to many people."

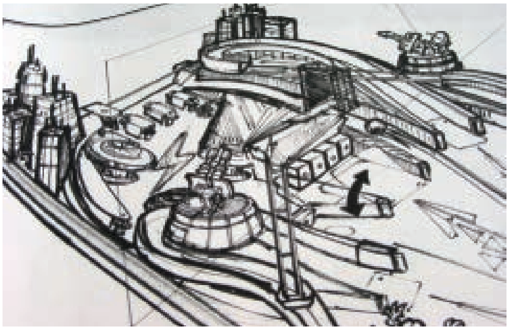
But any rancor vanished when the two men showed what they'd done. Everyone loved it, even the team developing the current version of Pinball 2000.

"I was blown away," says former engineering director Larry DeMar, no stranger to coin-op success as the co-creator of video hits *Defender* and *Robotron: 2084*. "The prototype worked so well that it was instantly clear to me that this was big."

But not only was it a big idea: it was an enormous undertaking. "Pinball teams would acquire a video game component," notes Gomez. "We needed display technology, artists, animators, cinema guys; the software team would have to expand with dedicated programmers for the video elements. We'd have to redesign assembly lines. The thing needed a new box. We were asking the company to turn its entire world upside down."

Williams' 50-person pinball team went into overdrive converting the prototype into a real product

Photography by Greg Maletic (left), and Duncan Brown



END OF THE LINE: (Clockwise from top left) The trapezoidal line on this sketch shows where the video images would appear on the pinball play-field; legendary pinball designer Steve Kordek — who started in the industry in the early 1940s — gazes at the last Williams pinball machine to roll off the assembly line; the Williams team gathers for a goodbye to pinball.

Photography by Greg Maletic (sketch), and Duncan Brown

and 18 months later, the first of the Gomez-Lawlor breed of Pinball 2000 machines, *Revenge From Mars*, launched in March 1999.

It was an unquestionable success, selling about 7,000 units. Given the economics of the time, 2,000 or 3,000 units was considered "break-even"; 5,000 denoted a hit.

The second Pinball 2000 machine, based on *Star Wars: Episode I*, sold well but underperformed relative to outsized expectations. In a market that wouldn't tolerate mistakes, Pinball 2000 had faltered, resulting in a surprise announcement from Williams: on Oct. 25, 1999, only eight months after Pinball 2000's introduction, the company would end its 55-year run in the pinball business to focus on video slots.

One can argue whether Pinball 2000 ultimately could have saved pinball at Williams; it's easier to make the case that the odds were so stacked against the product that it was destined to fail. Still, in the time they spent handcrafting Pinball 2000, Gomez and Lawlor achieved something remarkable in an industry not known for breakthrough innovation.

Today, Lawlor runs his own game design firm. He initially focused on designing pinball for Chicago's Stern Pinball. After a stint at Midway video games, Gomez now works at Incredible Technologies, a manufacturer of coin-op games and video slots, and in his spare time, still designs pinball for Stern.

Despite the death of the Pinball 2000 concept both Gomez and Lawlor remain committed to the maker ethos.

"My small company, Pat Lawlor Design, has a physical shop and tools that it takes to model ideas quickly," says Lawlor, "all because I believe very strongly in the 'skunkworks' approach."

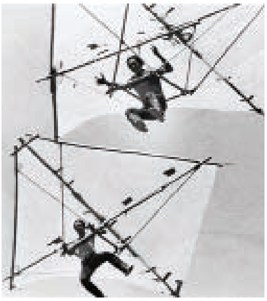
Says Gomez, "I currently use 3D and old 2D CAD tools, and yet the most powerful rapid development tool is actually making things with my hands."

» Want to learn more about pinball and the people who make it? Pick up a DVD of *Tilt: The Battle to Save Pinball*, the author's acclaimed behind-the-scenes look at the development and ultimate demise of Pinball 2000, available at makershed.com.

Greg Maletic (greg@tilt-movie.com) is a software designer and illustrator living in San Francisco.

Under a Blue Tarp

Build a hang glider from scratch. By Gever Tulley



GUMPTION GLIDERS: (Above) A short but successful flight on our PVC and tarp version. (Left) The 1970 photo that inspired our build: Bob and Chris Wills flying Bamboo Butterfly hang gliders designed by Richard Miller.

There's a photo on Wikipedia of two gleeful brothers flying hang gliders they've made from duct tape, plastic sheeting, and bamboo. We at the Tinkering School had been kicking around the idea of making a hang glider for a couple of years, and this picture convinced me that a group of 12- to 16-year-old kids could do it.

The photo shows a design referred to as the Bamboo Butterfly, but try as we might, we could only find one low-res scan of a handmade copy of the original plans. No matter — we had the picture and a dab of collective knowledge of aerodynamics to convince us that it was possible. Some might call this hubris, but we like to think of it as gumption.

The first hurdle was that we didn't have any bamboo, but we did have plenty of ¾-inch PVC pipe. The tinkerers immediately clued in to the fact that PVC is not a great substitute for bamboo. Compared to a 10-foot stick of bamboo, a 10-foot PVC pipe is like a heavy cooked noodle. They would have to figure out how to deal with that in the design.

The next big problem was scale. Trying to deduce dimensions from the photograph, they quickly discovered that the perspective was really distorting things. A note in the unintelligible plans implied that we wanted a "wing-loading" (the weight of the craft and pilot, divided by surface area of the wing) of between 1 and 2 pounds per square foot of wing. Some math ensued and we arrived at our first fixed dimension: the keel of the craft would be 15 feet long. We started cutting PVC.

As it took shape, the idea that someone was going to fly down a hill in this overgrown kite seemed alternately exciting and ludicrous. We couldn't stop laughing at how noodly the whole contraption was. Someone pointed out that we didn't have to keep it from drooping, we only needed to keep it from bending up. In a few moments the gang had tied dozens of guy wires from the leading-edge poles to the pilot cage. We were ready to fly!

While Tywen Kelly donned his protective gear, I tied a leash to the keel. I didn't want the kids getting more than a foot or two off the ground. After a brief discussion of technique, he ran down the hill — and didn't leave the ground. The wing was either stalling or nose-diving. This was going to take some real finesse.

Everyone took turns running down the hill at full speed. It was thrilling, and big hops were accomplished, but no real flying. After some discussion they decided that the pilots just weren't getting their weight far enough forward — the nose would go up and not come back down.

Back in the shop, they got the cage moved forward, and padded the cage bars that had given everyone armpit bruises. Then it was back up the hill for more tests.

Leo Berez made the first real flight on the very first run — the new cage position was helping! Not everyone who tried it before it started to fall apart actually flew, but everyone felt that it could fly, and some short glides were accomplished. At the end of the day, we were exhausted and happy. And that's all you really need from a project like this.

Gever Tulley (gever@tinkeringschool.com) is the founder of the Tinkering School.

Photography by Julie Spiegler (top), and *The Orange County Register* (bottom)

Inside Out

Brittny Badger's photos reveal the inner beauty of household appliances. By Laura Cochrane

There's a lot of beauty in a well-designed object and the parts that make it up. And the most solid designs are often found in items that you don't spend time thinking about, because you don't have to. They just work, effortlessly.

For her senior thesis at the Hartford Art School, 25-year-old Brittny Badger explored some of these devices of convenience that are often taken for granted. Inspired by a photo she saw of toy car parts laid on a white background, she disassembled and rearranged the components of small electric kitchen appliances, taking photos to document her final arrangements.

For her first piece, the West Hartford, Conn., artist gutted an electric handheld beater. Falling in love with the colorful, bendable wires and other shapes, colors, and textures of the innards, she went on a thrift store crawl, looking for more objects to take apart. The fact that the appliances were used only added visual interest. "They had much more character due to the nasty residue and stained plastic," Badger muses.

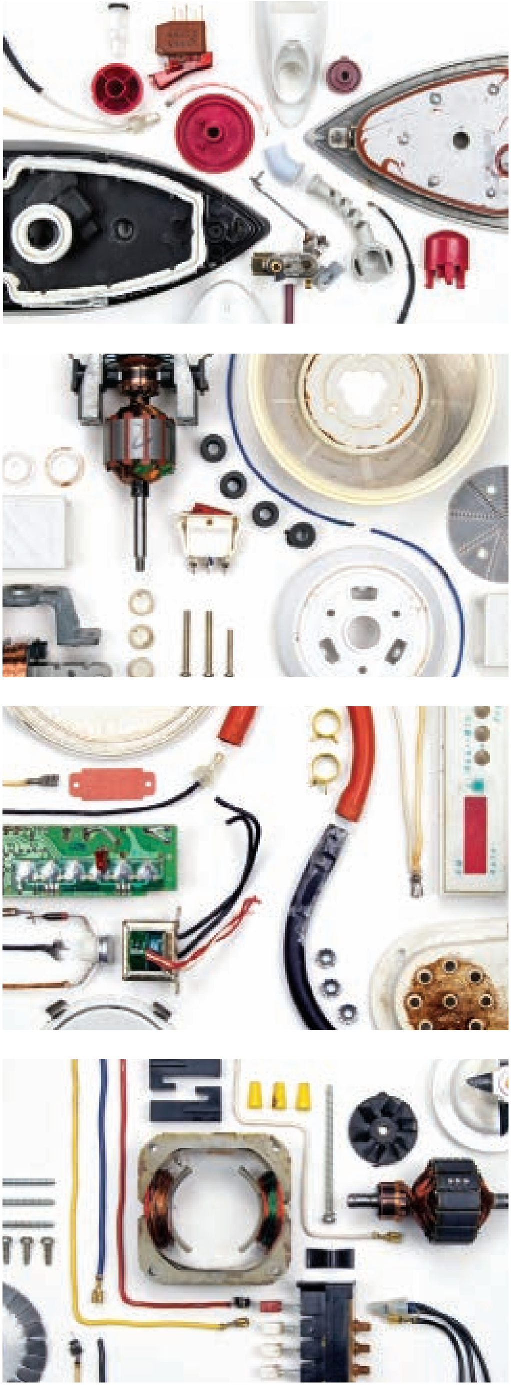
In total, she opened, rearranged, and photographed a blender, electric knife, handheld vacuum, sandwich maker, can opener, beater, coffee maker, clothes iron, juicer, popcorn maker, toaster, and waffle iron.

Freed from their plastic shells, the hardworking, blue-collar appliance parts are given room to play together aesthetically, instead of working together mechanically. Components that are normally motionless seem to gain movement and personality, to interact with each other.

Tendrils of rainbow-colored wires ripple outward, while screws, bolts, wires, and small plastic doohickeys outline and punctuate the larger, more task-specific parts. The variety of textures, finishes, and forms concealed inside these simple devices is breathtaking. It's visual, utilitarian poetry.

Badger is currently working on *At the Top*, a photo series of building tops and the surrounding sky. To see more of her work, visit flickr.com/photos/brittnybadger and her blog, brittnybadger.blogspot.com.

Photography by Brittny Badger



EXPOSED: Badger's series of disassembled appliance images includes (top to bottom) an iron, a juicer, a coffee maker, and a blender.

Laura Cochrane takes pleasure in simple things. She is the editorial assistant at MAKE.

Make: REMOTE CONTROL

No one gave us the push-button world of the Jetsons, so we're making it ourselves.

Photography by Robert Rausch

LAWNBOT400

Make an Arduino-controlled R/C lawn mower.

BY J.D. WARREN

Photograph by Robert Rausch

I have always hated mowing the lawn. I was the guy who only mowed when the grass got to be 6" taller than the neighbors' lawns — not because I don't like my neighbors, but because mowing was such a pain. After being hit by one too many rocks, I decided I no longer wanted to stand behind a mower while cutting the grass. I also realized that if I got a riding mower, I'd still be right in the middle of all that dust and pollen.

I started thinking, what if I could mow the grass from the back deck, or even the computer? To handle my 1-acre backyard's hills, dips, and rocks, an R/C lawn mower would have to be very sturdy, be controllable from a good distance, and have enough battery power to last several hours. I built the Lawnbot400 to meet these criteria.

MATERIALS

R/C transmitter and receiver that outputs a servo signal. Most do. I bought an ESky EK2-0420A 6-channel set on eBay for $50.

FOR THE R/C AND FAIL-SAFE CONTROLLERS:

ATmega168 IC chips with Arduino Bootloader (2) part #DEV-08846 from SparkFun (sparkfun.com)

Other components are available from radioshack.com.

Small pieces of perf board (2)

Insulated stranded wire, 22 gauge

28-pin sockets (2)

LM7805 voltage regulators (2)

16MHz crystal oscillators (2)

5V 1A SPDT switches (2)

Capacitors: 0.1μF (2), 220μF (4)

1kΩ ¼W resistors (6)

12V toggle switches (2)

Screw terminal blocks: 2-contact (19), 3-contact (2)

6×1 female pin headers (3) for the R/C

LEDs, any color (4) 3 for the R/C

330Ω ¼W resistors (4) 3 for the R/C

1N4001 1A diode for the fail-safe

12V 60A normally open automotive relay $6

40A–60A fuse for the fail-safe

FOR THE MOTOR CONTROLLER:

All components are available from digikey.com.

P-channel MOSFET transistors, 47A 60V (12) Digi-Key part #FQP47P06

N-channel MOSFET transistors: 52A 60V (12) and 200mA 60V (4) parts #FQP50N06L and #2N7000

47Ω bussed resistor networks (8) #4606X-1-470LF-ND

2-position screw terminal blocks (6) #ED1609-ND

Resistors: 4.7kΩ ⅛W (24) #CF1/84.7KJRCT-ND

PC board, 1-sided copper-clad, 3"×4½" #PC9-ND

Capacitors, 1,000μF or similar (4) #P5575-ND

LED, 3mm any color

Resistor, 330Ω–1kΩ ¼W for the LED

80mm PC cooling fan

TO-220 heatsinks, bolt-on or clip-on (24) (optional)

#8 bolts, 3" long (4) with matching nuts (12)

Power distribution block (optional) helps with wiring

FOR THE DRIVETRAIN:

Wheelchair motors (2)

Sprockets: 17-tooth (2) and 65-tooth (2) part #G13610 from goldmine-elec.com and part #127-12 from partsforscooters.com

¼" bolts, 4½" long (6) with matching nuts (18) and lock washers (6)

#25 roller chain, 10', with 2 universal links about $12

Drive wheels with bearings (2) part #36054 from Harbor Freight Tools (harborfreight.com)

FOR THE MOWER AND CARRIAGE:

Gasoline-powered push mower about $50 used

12V sealed lead-acid marine batteries (2) $20–$50

Metal stock, 36" lengths: 1"×1" angle iron (2); 2"×2" angle iron (2); 1"×1" square tubing (2); 1" flat steel $6–$8 each from Home Depot

Threaded rod, ⅝"×36" long (1) with matching nuts and washers (6)

½" bolts: ¾" long (20) and 2" long (10) with matching nuts, washers, and lock washers

Caster wheels (2) Harbor Freight #38944, $15

Scrap of plywood to carry the electronics

TOOLS

Drill press or electric drill, with ½" bit

Angle grinder and Dremel rotary tool

Voltage meter, wire strippers, and electrical tape

Ratchet set, Allen wrenches, and crescent wrench

Pliers, screwdriver, measuring tape, and level

Soldering iron (optional) if you make the breakout boards or motor controller

Welder (optional) but handy

FOR MAKING THE MOTOR CONTROLLER PCB (OPTIONAL):

Laser printer, magazine paper, clothes iron, acetone, Scotch-Brite cleaning pad, paper towels

Bowl of warm, soapy water

Hydrogen peroxide and muriatic acid for etchant

Glass baking dish or other shallow glass container large enough to hold PC board

Toothbrush or air pump

Chemical gloves and safety goggles

SUBSTITUTIONS

Here are easier (but more expensive) options for some of Lawnbot400's major components.

» R/C controller: Arduino Duemilanove $35 from Maker Shed (makershed.com)

» Fail-safe controller: Arduino Duemilanove

» H-bridge motor controller: Sabertooth 2×25 $125 from Dimension Engineering (dimensionengineering.com), or any other motor controller that accepts a standard 0V–5V signal

» Drivetrain: Pair of wheelchair motors with wheels already mounted to them

Functional Overview

Basically, if you took the wheels and handlebar off any old gas-powered push mower, bolted it into a sturdy metal frame with 2 electric wheelchair motors, and added the electronics needed to make it move, you'd have the Lawnbot400. I control mine with a standard hobby R/C transmitter and receiver, but with just a few modifications it could be made autonomous.

Steering the Lawnbot is simple. Move the left control stick up, and the left wheel moves forward. Move the right control stick back, and the right wheel moves backward. Both sticks forward and you go straight ahead. This is called "tank steering," and it gives the Lawnbot400 a zero turn radius (Figure A, following page).

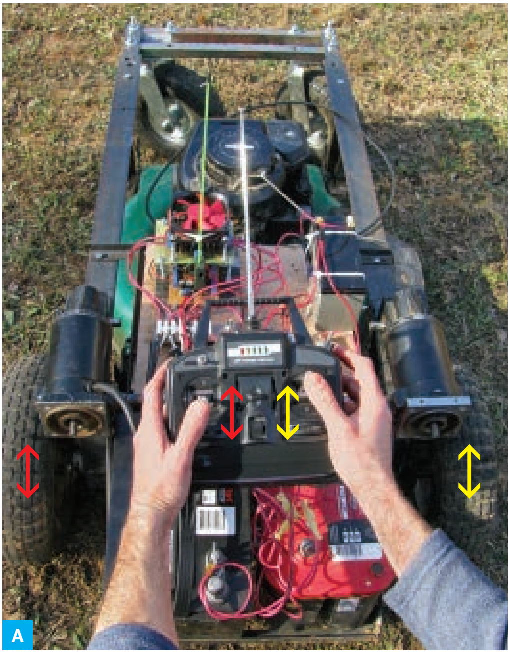
The pieces that enable this control are a bit more complex. The hobby R/C transmitter encodes the control sticks' positions and sends them to the receiver using pulse-position modulation (PPM), which encodes a value, such as the desired position of a servo, as the ratio of ON time to OFF time in a fixed-duration series of repeated pulses. But the H-bridge motor controller that supplies variable voltage to the wheelchair motors needs a simpler pulse-width modulation (PWM) signal, in which the pulses don't repeat within a fixed time frame. So I used an Arduino-based microcontroller to translate the PPM R/C signal into PWM for the H-bridge.

The H-bridge uses transistors to convert the 0V–5V PWM values into straight 0V–24V DC voltages running from the batteries to the motors in both directions. The wheelchair motors are electric, so the bot will drive even if the gas-powered mower isn't running. Instead of buying an H-bridge, I chose to build my own. (It should be noted that I didn't plan to take the easiest route in this project. Instead, I wanted to learn how each electronic part worked, so I'd know how to fix it if it broke.)

I didn't want to donate my Arduino to the project, so I made my own controller with screw terminals on each pin for secure connections during bumpy rides. Like an off-the-shelf Arduino, this board serves as a breakout board for the ATmega168 microcontroller chip, and it has its own 5V regulator (LM7805), 16MHz crystal, power LED, and reset button. I also added a header to the board for my R/C receiver to plug directly into. My board lacks the standard Arduino programming port and FTDI USB chip, so to use it, I simply program an ATmega chip in my Arduino, then swap it over.

With all of the above, I got the Lawnbot400 running successfully, and in the next version, I added a fail-safe to keep the bot from running away if it loses its signal. The fail-safe uses a second (even simpler) Arduino-compatible breakout board to read a third R/C channel, controlled by a toggle switch on the transmitter. The code reads this channel using the `PulseIn` method and sets a digital output pin accordingly. If signal is present, the output pin stays on, which uses a 5V relay circuit to keep a 60-amp relay open, to let the main 24V battery power reach the motor controller. But if the bot gets out of range or the switch is turned off, the channel reads `LOW` and motor power shuts off until signal is restored.

Both the R/C and fail-safe control boards were simple to build and cost around $12 each. Later, I figured out how to add fail-safe handling into the main R/C code, so you could use just one microcontroller chip with all 3 channels, but this would sacrifice some safety. If the sole ATmega goes crazy and stops responding, you're out of luck, whereas it's highly unlikely that both chips will fail at the same time. So I still use the separate, dedicated fail-safe.


A

Here's how I built my latest Lawnbot400; see the Substitutions box on the previous page for easier options that will have you mowing from your deck chair sooner.

Build Your Lawnbot400

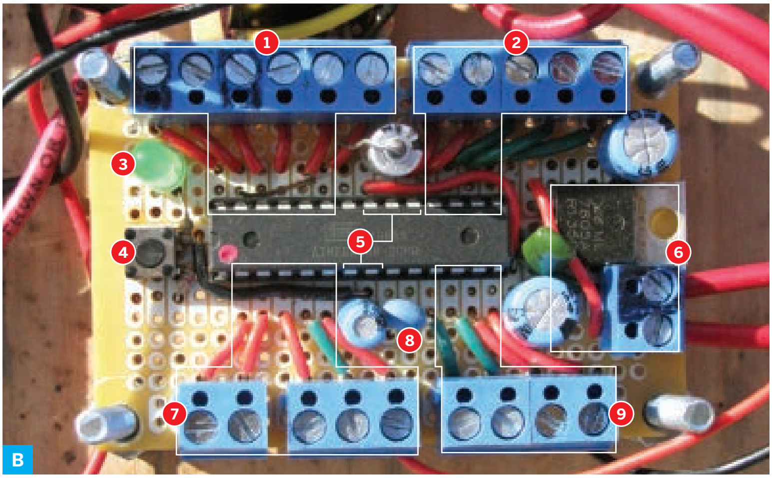
Time: **3–5 Days** **Complexity:** **Difficult**

1. Make the controller boards (optional).

You can use 2 Arduino boards (or just one) for the R/C and fail-safe controllers, but here's how I built my own simpler and semi-ruggedized versions cheaper. The fail-safe is optional but strongly recommended for safety. Visit makezine.com/22/rclawnmower for parts lists, schematics, and code.

The fail-safe board simply breaks out the pins from the Arduino's ATmega chip to screw terminal blocks at the edges of the board. I put in a few capacitors for the 7805 voltage regulator and a crystal oscillator for the external clock, and that's it. The fail-safe relay and fuse are too large to fit on the board but can be mounted nearby.

Photography by J.D. Warren



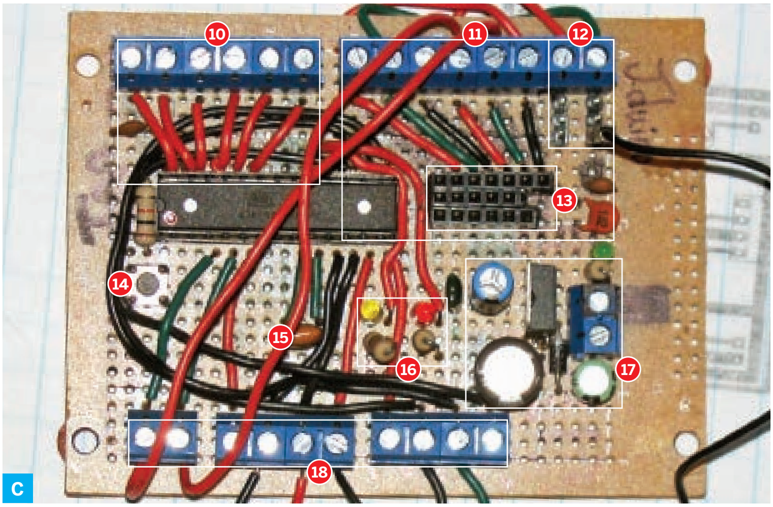


Figure B:

1 Pins 23–28 of the ATmega go directly to screw terminals for analog pins 0–5.

2 Pins 15–19 of the ATmega go directly to screw terminals for digital pins 9–13 (from right to left).

3 The power LED is tied to +5V and a 330Ω resistor to ground.

4 The reset button goes from ground to pin 1 of the ATmega. Pin 1 also needs a 10K pull-up resistor. If you don't want a reset button, put a 10K resistor from pin 1 to +5V.

5 Pins 7, 20, and 21 are tied to +5V. Pins 8 and 22 are tied to ground.

6 The power supply consists of a 7805 5V regulator, 2 capacitors, and a screw terminal. The 7805 can accept up to 36V DC input and will deliver 5V to the ATmega. The green capacitor is a 0.1µf decoupling capacitor and the larger blue one is a 220µf 10V.

7 Pins 2–6 of the ATmega go directly to screw terminals for digital pins 0, 1, 3, and 4.

8 The 16MHz crystal resonator goes to pins 9 and 10 of the ATmega (center pin of the resonator to ground).

9 Pins 11–14 of the ATmega go directly to screw terminals for digital pins 5–8.

Figure C:

10 Pins 23–28 go to screw terminals for analog pins 0–5.

11 The first 6 screw terminals go directly to the 6 channels from the R/C receiver. None of these wires are connected to the ATmega. You must route the wires from these screw terminals to the desired ATmega pin's screw terminals.

12 These 2 screw terminals are connected to the 2 sets of male servo pins below. The top pin is signal, middle pin is +5V, and the bottom pin is ground.

13 This header is for the R/C receiver. The top row breaks out each channel to a screw terminal. The second row is +5V. The third row is ground.

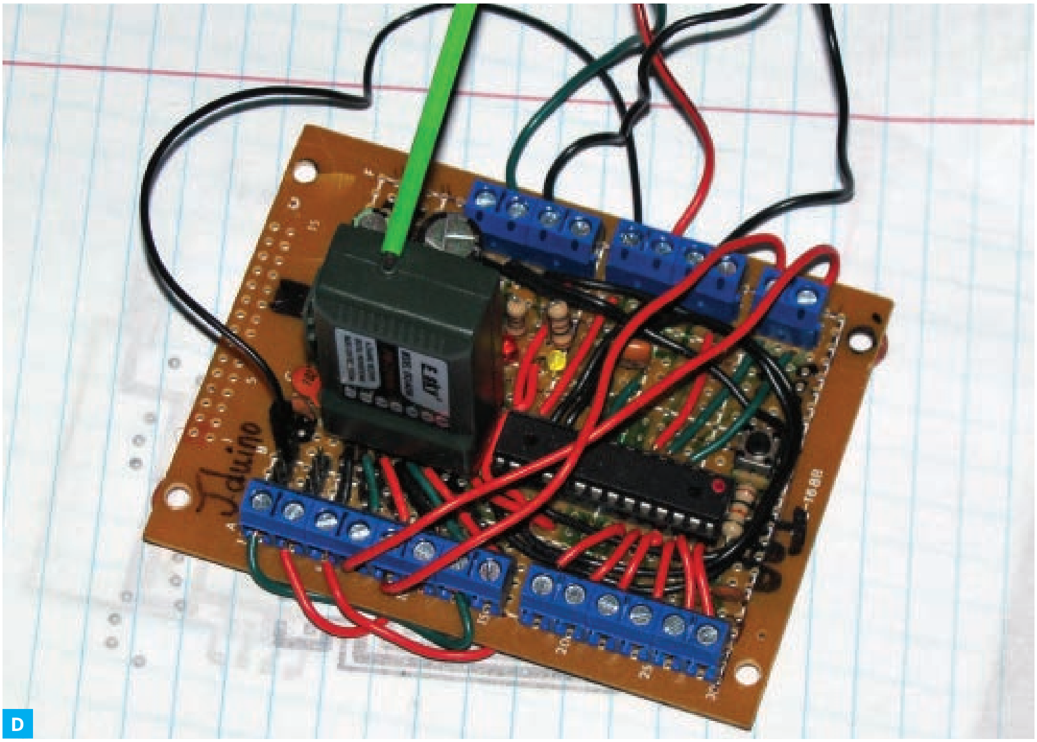
14 The reset button goes from ground to pin 1 of the ATmega. Also use a 10K pull-up resistor from pin 1 to +5V.

15 16MHz crystal resonator to pins 9 and 10 of the ATmega.

16 Two LEDs with 330Ω resistors from digital pins 12 and 13 to ground. I use these as neutral indicator lights. When the control sticks are centered, these lights come on, which helps when fine-tuning the R/C transmitter. I sacrificed any other use of these pins for the LEDs.

17 The power supply: a 7805 5V regulator, screw terminal, and 2 capacitors. I put in several capacitors I had lying around (they must be above 10V rating), but it only needs a 220µf capacitor at the output and a 0.1µf decoupling capacitor close to the ATmega. If you're not using bulk capacitors in your motor controller, use several here. I also added a 1N4001 diode to protect against reverse polarity.

18 Screw terminals for digital pins 2–11. I don't use digital pins 0 and 1 on this board, and pins 12 and 13 are being used by the 2 neutral indicator LEDs.



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The R/C controller uses a slightly larger piece of RadioShack perf board to carry the same components as the fail-safe board, plus 2 LED motor indicators connected to digital output pins 12 and 13, and a port for the R/C receiver consisting of three 6-pin female headers stacked together.

The control pins from this R/C port connect to another screw terminal block on the board. I could have simply used jumper wires to connect the R/C receiver to power and to the microcontroller, but the header and screw terminals make the connections stronger and very easy to reconfigure.

The 6×3 grid of connector pins on my R/C receiver are mapped with the first row of pins carrying each channel, the second row all +5V, and the third row all ground. You want to find 2 channels that are controlled by up/down movements on your transmitter, such as the ones used for throttle and elevation. To do this, go down the line plugging a servomotor into each channel. Move every control stick until the servo moves, then write down which channel is controlled by what stick. Decide which 2 channels to use for the Lawnbot motors.

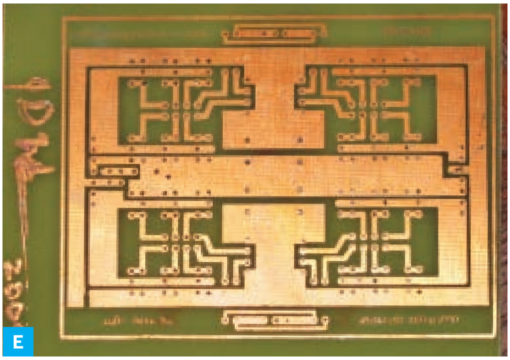
Connect these 2 channels on the R/C receiver to pins 4 and 5 of the microcontroller chip (which function as Arduino digital pins 2 and 3, the only 2 external interrupts). For the receiver's power, I jumpered wires over from my Arduino-based R/C controller's +5V and Ground pins.

2. Load and test the code.

Download the code from makezine.com/22/rclawnmower and load it onto your Arduino(s). To check the R/C code from your computer, keep the Arduino plugged into the USB port, connect the R/C receiver as in Step 1, turn the transmitter on, and click on the Serial Monitor button in the Arduino IDE. Moving the left control stick should change the reading for your left motor's channel, and the right stick should control the right channel. If not, swap the inputs.

The on-pulse duration readings should range from 1,000 to 2,000 microseconds, showing 1,500 when the control stick is centered. If not, adjust the stick's trim control on the transmitter, or change the max and min values in the code to match the range of readings you see in the serial monitor.

If you're in the field using standalone controller boards, you can use a multimeter to probe the Arduino pins' voltage outputs while moving the control sticks. Arduino digital pins 5 and 9 (ATmega chip pins 11 and 15) run forward and reverse for the left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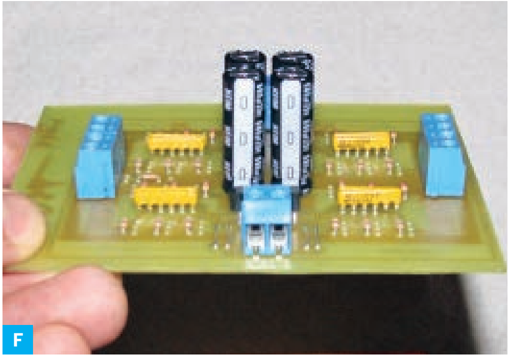
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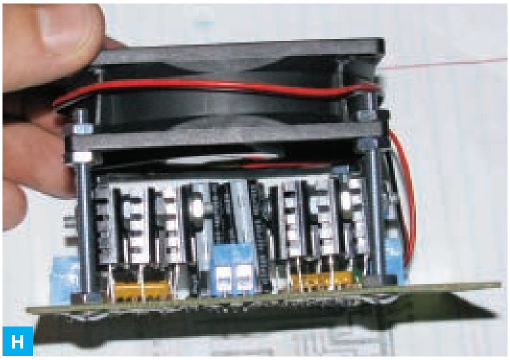
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motor, and digital pins 6 and 10 (chip pins 12 and 16) control the right. Probe the pins one at a time, checking for a good 0V–5V PWM signal. Or use LEDs for a quick visual test; place them short leg to ground, long leg to the Arduino output pin, and look for the control stick to work like a dimmer.

3. Build the H-bridge (optional).

You can buy an H-bridge motor controller like the Sabertooth 2×25 from Dimension Engineering, but if you feel like an adventure, build your own. Here's how I built one on a custom PC board for about $35.

Download the circuit board layout and schematic files *triple8.brd* and *triple8.sch* files from makezine.com/22/rclawnmower. Also download Eagle from cadsoft.de; the free version is fine.

Open *triple8.brd* in Eagle and use a laser printer to print only the bottom layer on a piece of glossy magazine paper. I have tried many types of paper, and had the best results with my wife's *Cosmopolitan* magazines. Find pages with plain black text only, like the backs of prescription drug ads, where they list the side effects. Feed the page into the printer manually to make sure it goes in straight.

Turn your iron to its high setting. Scrub the PC board's copper side with a Scotch-Brite pad and clean it with acetone and paper towels several times.

Place the print facedown on the copper-clad board and place the iron on top. Apply pressure and heat for about 3 minutes, moving every 30 seconds.

Let the board sit for a few minutes, then soak it in a bowl of warm, soapy water for 30 minutes. After soaking, rub the paper off with your thumb until only black toner traces remain.

Mix an etchant solution with 2 parts hydrogen peroxide to 1 part muriatic acid. Pour the etchant over the copper board in a glass dish and agitate it for about 10 minutes with a plastic implement or air pump. When the unmasked copper has all dissolved, rinse off the board and remove the black toner with more acetone and paper towels (Figure E).

CAUTION: Always wear chemical gloves and safety goggles while working with etchant, and take care not to drip or splash.

Drill holes in the PCB at every hole location. Solder the components on the board, following the schematic. Start with the resistors and terminals, and finish with the transistors and capacitors, making sure all the transistor gates point toward the resistor networks that drive them (Figures F and G).

Finally, attach heat sinks to the 47A and 52A


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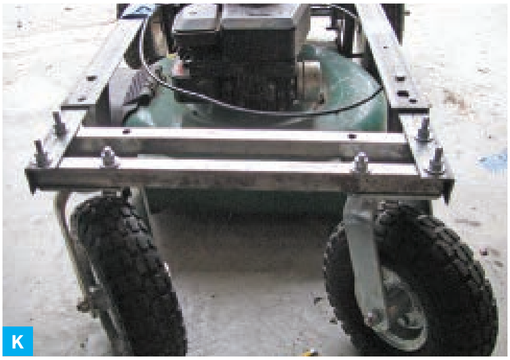
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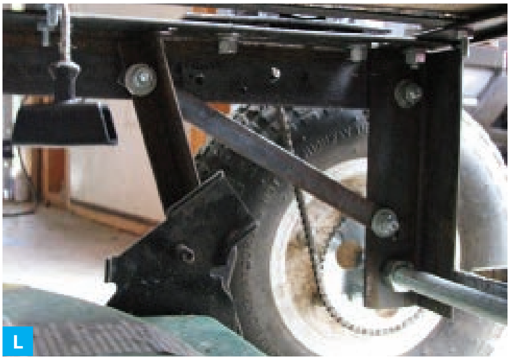
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transistors and bolt a PC cooling fan on top, aimed to draw air away from the board (Figure H, previous page).

To test your H-bridge, hook it up to a 12V power source, following the schematic. Apply your Arduino's 5V to each input, and use your voltage meter to look for 12V at the 2-pole motor terminal outputs.

4. Mount the wheel sprockets.

The easy way is to find a set of wheelchair motors that have wheels already mounted. I couldn't find any in my price range, so I just went with the motors and found my own wheels. I didn't think the motors would be strong enough to drive the wheels directly, so I opted for a 17:65 chain drive.

To mount the sprockets to the wheels, I drilled matching sets of 3 holes aligned around the centers of the drive wheels and the 65-tooth sprockets. Then I bolted the sprockets on and tightened them up against the inside hubs as much as possible (Figures I and J). I also welded the sprockets to the hubs to keep them centered. Welding isn't necessary, but it helps.

5. Build the frame.

I made a simple rectangular frame and suspended the lawn mower body underneath it using 4 lengths of angle iron bolted to the mower's original axle holes. You'll want to custom-size your frame to fit your particular mower, and if something doesn't line up exactly, you may have to use your creativity. Luckily, the dimensions don't all have to be perfect.

Begin planning your frame by measuring your lawn mower's footprint and height. The frame's width should match the mower's original wheelbase, and its length must let the front caster wheels swing 360° without hitting the mower deck. Its height should allow you to adjust the deck to sit at its original height range. For my frame, this meant 24" wide by 48" long by 18" tall.

I constructed my frame by cutting, drilling, bolting, and welding together lengths of angle iron, square tubing, threaded rod, and flat steel. The main part of the frame consists of 2 long pieces of 2" angle iron that run from front to back, one on each side. In front, these runners are bolted to 2 crosspieces of square tubing, which in turn bolt to the mounting plates of the 2 caster wheels (Figure K).

In back, the left and right runners are held up level by vertical angle-iron risers that connect down to the drive wheel axle. The axle consists of a length of threaded rod that passes through a hole in the bottom of each riser, held in place by nuts on either


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side. The drive wheels have built-in bearings, so they attach onto the ends of the axle with another nut, sprocket side in.

Angle-iron crosspieces connect the risers' tops and bottoms together in back, forming a box shape at the back of the frame. Flat steel braces further reinforce the risers by angling up diagonally from the bottoms of the risers, near the axle, to the left and right runners (Figure L).

6. Mount the motors.

The motor mounts were the most difficult part of the frame to plan. The motor sprockets need to align precisely with the wheel sprockets, but the motor positions must also be adjustable, to set proper tension on the chain. I mounted the motors to 8" lengths of angle iron, which in turn bolted through longitudinal slots in the runners, so they could slide forward and backward before tightening down.

The angle-iron plates have 2 holes for mounting, one in front of the motor and one behind it (Figure M). To mark where the slots need to be, line up the mounting plates (preferably with the motor mounted) onto the runners as far back as you can without hitting any other bolts underneath the frame. Use a Sharpie to mark the mounting hole positions on the runners, then move the motors forward 2" and mark the new positions. I drilled one hole at each mark and used a Dremel tool with a cutoff wheel to cut out the rest.

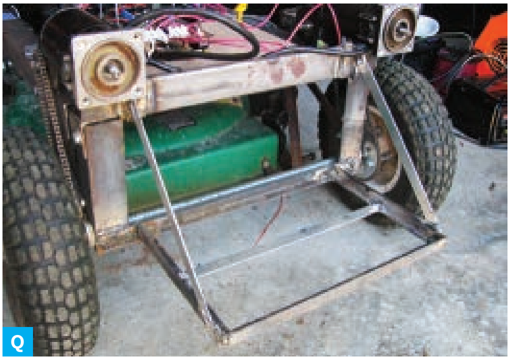
Mount the sprockets to the motors' shafts, using a Woodruff key if your motors have a slotted bore. With the motors slid all the way toward the back of the frame, wrap the #25 chain around each motor and wheel sprocket pair, and mark where they overlap. Check that they're the same length for both sides, or else the bot won't drive straight!

Cut the 2 pieces of chain and connect them around the sprockets using the universal chain links. To tension the chains, loosen the motor mounts and slide them forward until there's good tension on the chain, then tighten the bolts back up (Figure N).

Now you can try generating some electricity. Connect a voltage meter to one set of motor terminals, push the bot around, and watch the motor work in reverse as a generator.

7. Attach the mower deck.

You need to suspend the lawn mower deck level, at its normal working height. Make sure the mower's original wheels are all adjusted to their center position. Measure the wheels' radius and subtract it from the height of the Lawnbot frame. Cut 4 pieces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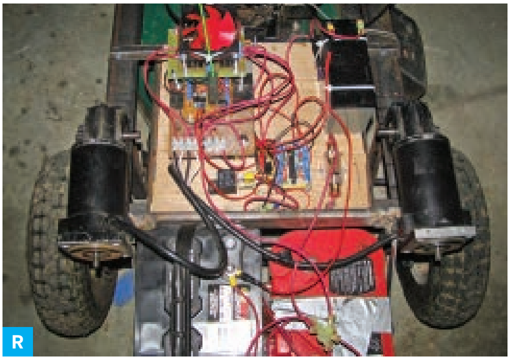
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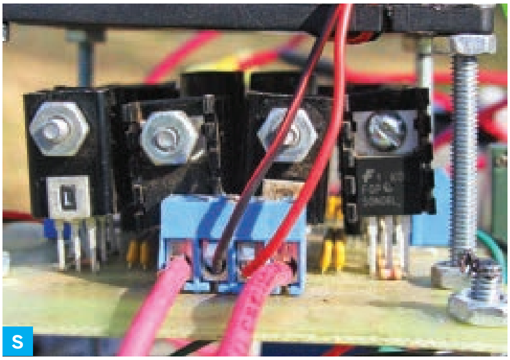
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of 1" angle iron to this length; these are the hangers that will attach to the top of the frame and suspend the deck. The bottom holes should fit the mower wheel shafts, and the top holes will be the standard ½" used for bolting the frame together.

Once you have all 4 hangers installed, install the mower deck and tighten the bolts. The deck should hang about 2"–3" above the ground (Figure O, previous page). Make sure the front wheels can swing all the way around with at least ½" clearance from the deck (Figure P).

8. Install the electronics.

To hold my 2 large marine batteries, I welded a rack to the back of the frame (Figure Q). This may not be necessary if you're using smaller batteries.

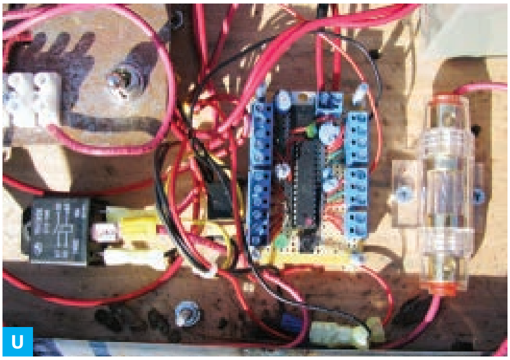
Now it's time to connect everything together and hope it works! I mounted all the electronics to a scrap of plywood bolted on top of the frame. A block of wood on the left carries the R/C controller, the H-bridge and fan on top, and a power distribution block along the back. The rest of the plywood holds the fail-safe board, relay, and fuse, and a battery for all the 5V electronics (Figure R).

If you're using two 12V batteries to achieve 24V, run a heavy-gauge jumper from the negative pole of one battery to the positive pole of the other. Plug the fuse from the free positive battery pole into the power distribution block.

Both Arduino control boards can connect to a 12V battery for power. I actually used three 12V batteries, 2 big ones for the motors and a smaller one dedicated to the electronics, so they're unaffected by current draw during fast reversing and takeoffs. But you can just as easily connect them to the main battery power supply.

Use the power distribution block to route power and motor wires to the motor controller, making sure you have the correct polarity (Figure S). Connect the R/C controller to the motor controller: Arduino digital pins 5 and 9 (ATmega pins 11 and 15) run to inputs A and B on the H-bridge for the left motor's forward and reverse, while digital pins 6 and 10 (ATmega pins 12 and 16) go to motor controller inputs C and D (Figure T).

Hook up the fail-safe following the schematic *fail-safe.sch*, so that the controller uses an offboard 5V relay to switch the larger, 60A power relay (Figure U). This code turns the relay off unless it receives a microsecond value between 1,900 and 2,100, which corresponds to an R/C channel that's fully on, like from a toggle switch. The first R/C radio I used had a



U

switch like this, but not the second one, so I desoldered the pot from one of its left-right joysticks (channel 3, I think) and replaced it with a small DPST switch, mounted to the front of the transmitter.

If you connected everything correctly, you should be cutting grass right now.

Operation

To operate the Lawnbot400, turn on the transmitter and flip the power switch on the bot. The Arduino breakout board should power up and the Neutral indicator lights on the R/C control should come on. These LEDs, connected to Arduino digital pins 12 and 13, indicate when the signal is in the neutral range. If they aren't lit, adjust the trim on the transmitter until they are.

Time to crank up the lawn mower engine, and remember to prime the bulb. Flip the switch for the fail-safe channel on the transmitter, and the motor controller should power on, along with the cooling fan. Now all you have to do is drive.

The Lawnbot400 will scoot across the yard at 5mph–10mph, which may be faster than optimal for mowing the grass. Proper cutting speed depends on the power of the lawn mower engine and the condition of the grass. If you use the cheapest mower available (like me), the engine will bog down if the grass is too tall or wet. But if you mow before it gets too tall, you should be able to go as fast as you want. With a little practice, you'll learn to adjust the speed based on the sound of the engine and how hard it's working. At worst, the mower dies and you drive the bot back over to you to restart it.

My fears about the bot's ability to pull itself up a large hill were put to rest when I took it to a friend's property and watched it devour ¼ acre of woods with no problems. I was further convinced when it carried me (155lbs) across the yard and up a hill at a reasonable speed, without a hitch.

V

Photograph by Robert Rausch (V)

Going Further

How about adding ultrasonic sensors, wireless cameras, and an XBee wireless link? I got an ArduPilot with GPS for Christmas, so we'll see what happens there. I also plan to connect an electric motor to the lawn mower drive shaft to charge the batteries, which will also act as an onboard electric starter for the engine in case it dies during operation.

To automate the process, I'd start by mowing the grass with the R/C remote while using a GPS logger to record its movements. Then the ArduPilot would guide the Lawnbot through the recorded GPS path, using sensors to keep it from hitting anything the GPS didn't catch. Of course, I'd be inside, watching via camera while enjoying a cold beverage.

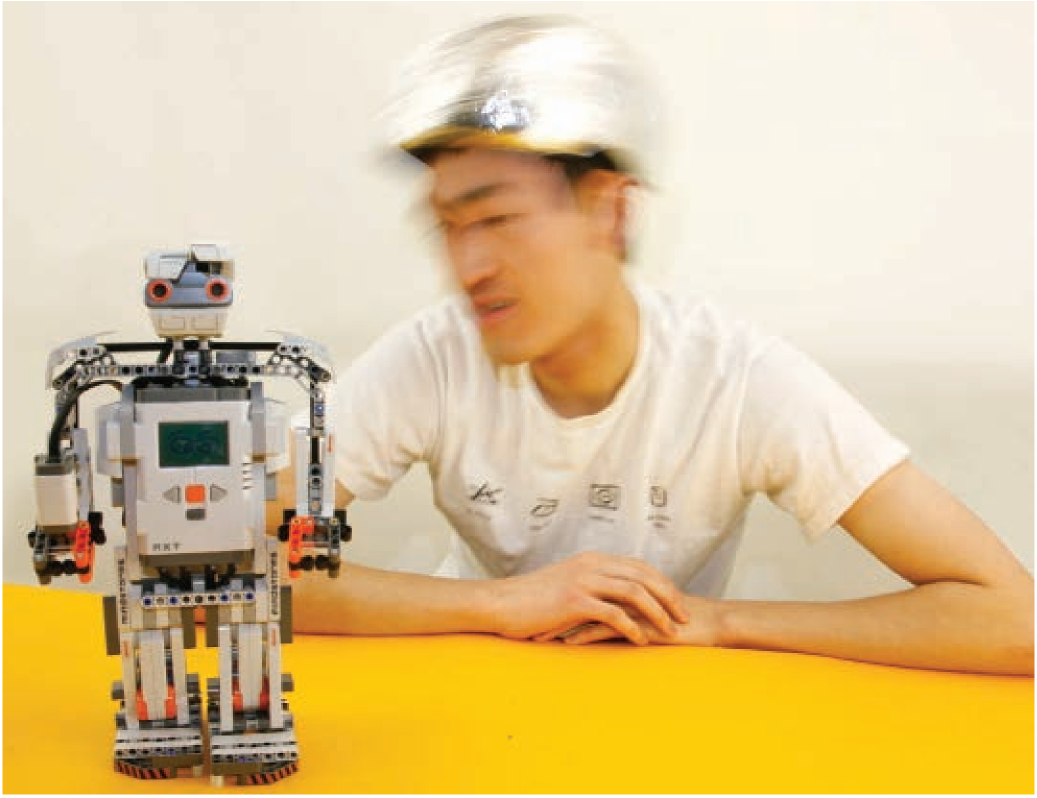
+ Find parts lists, schematics, code, and videos of the Lawnbot400 at makezine.com/22/rclawnmower.

J.D. Warren is a 27-year-old apartment manager and electronics hobbyist from Pinson, Ala., who spends most of his free time with his wife and three kitties or tinkering in his workshop. rediculouslygoodlooking.com

THE MIND SURFER

This Wiimote hack will convince your friends you've broken the mind-machine barrier.

BY MARK ULRICH

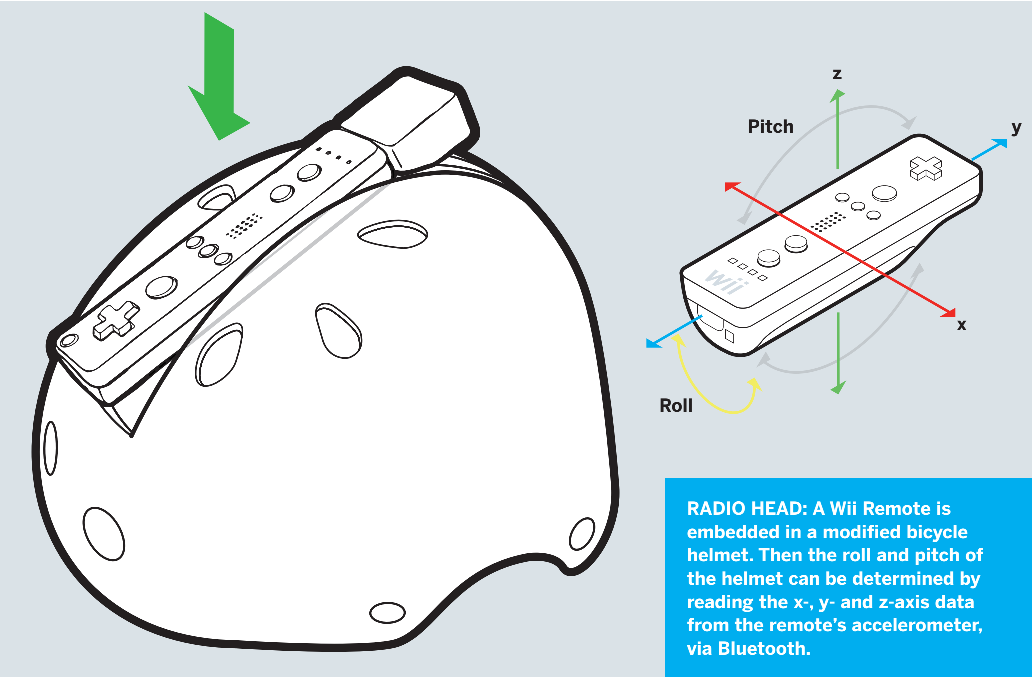


Photography by Sam Murphy

In recent years, researchers have developed technology that allows people to control computers and wheelchairs with their brain waves. My Mind Surfer is a helmet that seems to allow its wearer to control a toy vehicle via brain waves, but its technology is based on something much simpler. It has a Nintendo Wii Remote hidden in it.

Ask a friend to wear the Mind Surfer and tell him if he wants the cursor (or robot, or game character) to move left, he must imagine the left side of his head growing warmer or heavier as he "concentrates his brain's electrical energy." Chances are, he'll subconsciously tilt his head a couple of degrees to the left. The Wiimote detects the tilt, and your unsuspecting victim will be astounded to see that your helmet can "read" his thoughts!

The Nintendo Wii Remote can sense the magnitude and direction of tilt relative to gravity, and convert these into outputs for the device of your choice. You have myriad programming options to choose from; I've used GlovePIE and LabVIEW to control a cursor and a Lego NXT robot, respectively, but what I've outlined in this article is the simplest option: a Windows program called WiinRemote.



RADIO HEAD: A Wii Remote is embedded in a modified bicycle helmet. Then the roll and pitch of the helmet can be determined by reading the x-, y- and z-axis data from the remote's accelerometer, via Bluetooth.

Illustration by Julian Honoré/p4rse.com

Functional Overview

The Nintendo Wii Remote provides the Mind Surfer with a nicely bundled 3-axis accelerometer and Bluetooth (2.4GHz-band) radio. The accelerometer measures acceleration relative to free-fall; an accelerometer falling into a bottomless pit would measure 0*g* on each axis. A Wiimote sitting flat, face up on a table, would read 1*g* force on the vertical z-axis and 0*g* on the flat y and x axes, and as you tilted the Wiimote to the right the z-axis would decrease and the x-axis would increase.

If we assume that a person wearing the Mind Surfer is only tilting her head, not changing her location, we can use the accelerometer data to determine the tilt of the user's head relative to gravity.

NOTE: Accelerometers cannot detect yaw (turning/rotating the head left or right), only roll (tilting the head right or left, bringing the ear slightly closer to the shoulder) and pitch (tilting the head forward or back).

A computer receives and processes the accelerometer data via Bluetooth and sends outputs to the cursor, while a redecorated bicycle helmet provides a good casing to hide the Wiimote from inquisitive users and keep it oriented with the user's head. By creating a cradle with a cover, you allow the Wiimote to be moved easily in and out of the Mind Surfer when you switch back to playing Wii Tennis.

MATERIALS

Computer, Bluetooth-enabled preferably Windows XP with BlueSoleil Bluetooth software
Nintendo Wii Remote $50
Bike helmet preferably old
String (optional)
Rubber bands (1 or 2)
Duct tape
Decorative tape I used shiny aluminum foil tape, but duct tape in the color of your choice will work just fine.

TOOLS

Keyhole saw
Cutting pliers just in case the saw gets stuck
Scissors

Build Your Mind Surfer

Time: An Afternoon **Complexity:** Moderate

1. Process Wiimote data with your computer.

Many different Wiimote hacks are available online. One of the easiest programs to set up is WiinRemote (which outputs to your cursor), as I'll outline here; Mac users can download DarwiinRemote.

More programming expertise is needed to use GlovePIE (which can simulate inputs for a variety of games) or LabVIEW (which I used to control a

Lego NXT). Links to all of these are available in the Resources section, on page 56.

NOTE: Programs like WiinRemote are freeware, haven't been fully tested, and may cause problems if they aren't fully compatible with your system.

1a. On your Wii Remote, press and hold buttons 1 and 2 to make the Wiimote discoverable. (Make sure your Wii system is off so it doesn't automatically connect.)

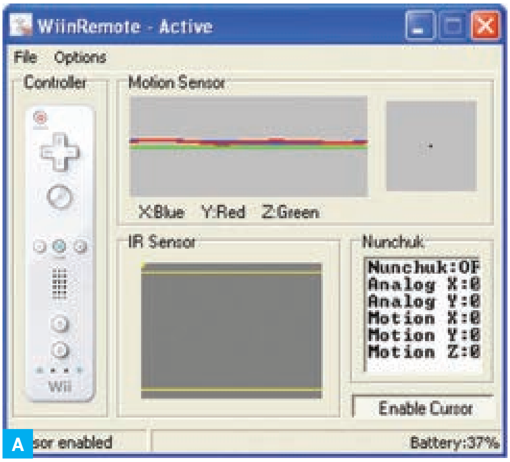
1b. On your computer, search for new Bluetooth devices. The Wiimote will have "Nintendo" in its name.

1c. Connect to the Wiimote without using a passkey or code, and wait for the drivers to automatically install.

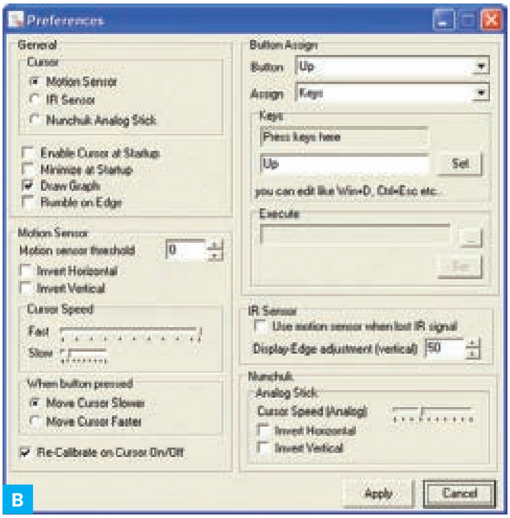
1d. Launch *WiinRemote.exe* (Figure A). If the program isn't updating the Motion Sensor graph as you move the Wiimote, then it may not be compatible with your system; try running it on a Windows XP machine with the BlueSoleil Bluetooth stack.

1e. In WiinRemote, select Options ⇒ Preferences (Figure B). In General preferences, disable the Rumble on Edge feature (unless you want your helmet buzzing when the cursor hits the edge of the screen).

In Motion Sensor preferences, set the threshold to 0 so that small motions will register. Crank up Fast Cursor Speed all the way to the right so that small tilts make a big difference. Finally, check Recalibrate on Cursor On/Off, so that if your volunteer suddenly shifts, you can easily calibrate to his new position by first pressing Ctrl-S to stop and then Ctrl-S to start again.



A



B

2. Build the Mind Surfer helmet.

If the bike helmet is old enough, you may be able to easily separate the plastic casing from the helmet to make cutting easier.

WARNING: This hack will instantly render the helmet unsafe for bicycling.

2a. Cut a rectangular, Wiimote-sized slot centered in the top of the bike helmet using the keyhole saw and cutting pliers. You can cut all the way through on the sides, but leave some tabs of helmet foam at the front and back to support the Wiimote.

Now add layers of duct tape to the sides of your cutout to make it a snug fit so the Wiimote doesn't jostle around. Tie one or two rubber bands across the top of your cutout using string (Figure C).

2b. Decorate and disguise the bike helmet by layering the decorative tape around the sides (Figure D), but don't cover up the rectangular cutout yet.

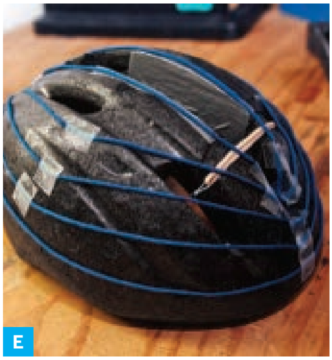
Optionally, you can embed string under the tape to create a layered, mystery technology effect (Figure E).

2c. To prevent the user's head from touching the Wiimote, layer the inside of the helmet with duct tape stretching across the rectangular cutout. Add a backing layer of duct tape where the tape faces the Wiimote, putting sticky sides together, so that both outer sides —touching the head and touching the Wiimote — are smooth (Figure F).

2d. Finally, create a top cover for the Wiimote slot out of duct tape (again with the option of embedding string), and add a backing layer to all but the outer ½". Leave this ½" perimeter sticky to make the cover stick to the helmet (Figure G). Insert the Wiimote, slap on the cover, and you're good to go!


C


D


E


F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How to Use the Mind Surfer

WiinRemote's default settings will make the cursor move toward the bottom of the screen if you tilt your head forward, and toward the top of the screen if you tilt your head backward. To move the cursor side-to-side, keep in mind that you must tilt, not rotate, your head.

Minimize the WiinRemote window and demonstrate the Mind Surfer to a friend, challenging her to tell you where to move the cursor and proving (by tilting your head imperceptible amounts) that you're controlling it with your brain waves alone.

Press Ctrl-S once to disable the cursor while you put the helmet on, and again to enable it and recalibrate it to your current orientation (when you enable it, your current angle becomes the zero point).

Then see if your friend's mind is strong enough. Tell her, "Sit in a chair with the helmet on, relax, and concentrate. Stay still to minimize vibrations. Imagine one area of your head (front, right, left, back) growing warmer and heavier as you concentrate your brain's electrical energy. The cursor will move in that direction."

About one-third of people will miraculously control the cursor. Another third will need a little more encouragement ("Try imagining that your right ear is hurting a lot, that someone is tugging on it"), while the last third either will find no correlation between where they want the cursor to go and where it does go, or will figure out what's really going on.

Controlling a Device with the Mind Surfer

If you're interested in creating your own program to control the device of your choice using LabVIEW or GlovePIE, use the textbook formula to convert accelerations to tilt:

$$\alpha = \arctan \frac{g_y}{\sqrt{g_x{}^2 + g_z{}^2}}$$

$$\beta = \arctan \frac{g_x}{\sqrt{g_y{}^2 + g_z{}^2}}$$

α: angle of pitch
β: angle of roll
g_x: acceleration in x-axis (oriented left/right)
g_y: acceleration in y-axis (oriented back/front)
g_z: acceleration in z-axis (oriented up/down)

However, in our case the tilt of the Wiimote won't vary more than 10°, so the following formulas can be used to find the direction of tilt.

$$\alpha = kg_y$$
$$\beta = kg_x$$

k: constant

To control a simple 2-wheeled robot, you would send:

$$\text{left motor} = \alpha + \beta$$
$$\text{right motor} = \alpha - \beta$$

If someone wearing the helmet tilts his head forward 1° then the robot will move forward at (depending on k) 10% power. If he tilts forward 2° and left 1° then the robot's left motor moves forward at 10% and right motor at 30%, so the robot moves in an arc to the left.

If you want a real challenge, figure out how to receive gyroscope data from the Wii MotionPlus controller extension for a more accurate, less bumpy Mind Surfer.

The design of the Mind Surfer revolved around my notions about how humans interact with machines, but it also led me to a deeper appreciation of the union between mind and body.

H

I

RESOURCES

Here are several programs you can use to receive data from a Wii Remote:

WiinRemote
onakasuita.org/wii/index-e.html
One of the easiest programs to set up for Windows, WiinRemote automatically outputs to your cursor, but it can't be easily customized to respond to very small tilts.

DarwiinRemote
sourceforge.net/projects/darwiin-remote
Like a WiinRemote for Macs, it automatically outputs to your cursor.

LabVIEW interface to Wii Remote
decibel.ni.com/content/docs/DOC-1353
The program I originally used for the Mind Surfer, LabVIEW, has sample programs available to receive data from the Wii and can easily be customized for many applications.

GlovePIE glovepie.org/glovepie.php
A popular program featuring both a GUI and a code interface that can receive inputs from various controllers, including the Wii Remote, and output them as mouse, keyboard, or joystick controls.

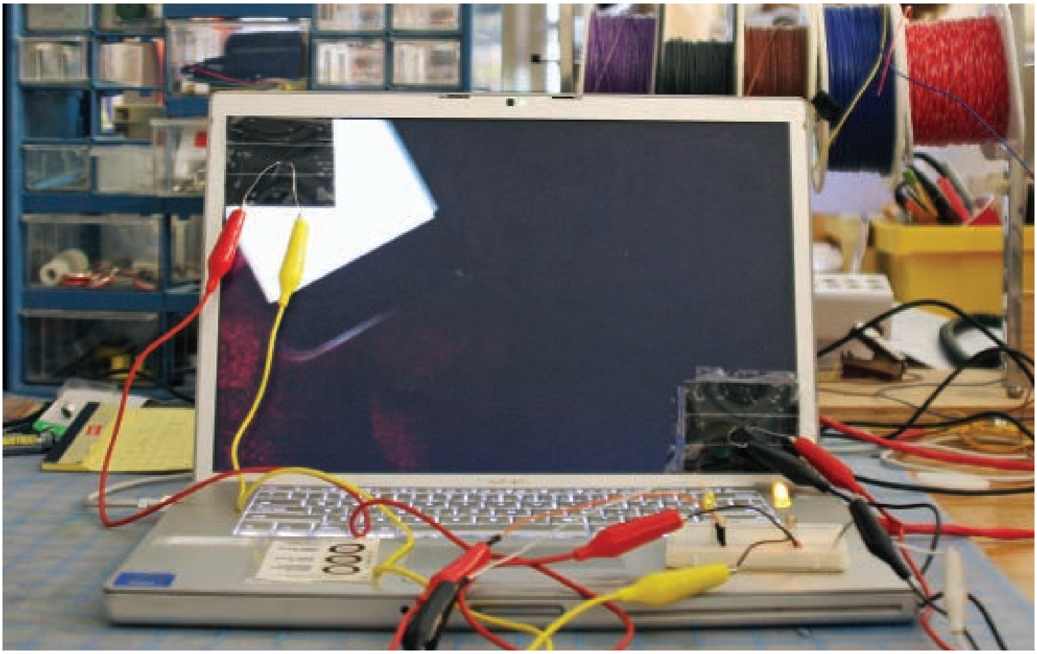
To see video of the Mind Surfer controlling my Lego NXT robot, check photopixels.com/thebakken/video.

Mark Ulrich lives in Minneapolis and is currently a senior at Southwest High and captain of the school's FIRST Robotics Team. He's interested in studying computer science.

EASY HOME CONTROL VIA WEB CHAT

Switch stuff at home from anywhere, with this screen-to-photosensor hack.

BY LEE VON KRAUS



Photograph by Ed Troxell

If you have pets or children that you need to feed or check on via the internet, here's a cheap and easy way to control motors, lights, and other devices at home from another computer online, like the one at work. You can set this system up in minutes and it requires no programming. All you need is a webcam, a flashlight, a standard computer running free software, and about $15 worth of analog electronics you can buy at RadioShack.

The system works through a Yahoo Messenger video chat connection between your home computer and any remote computer. But instead of showing people talking, the video stream conveys simple control information that you "encode" using a flashlight on a plain dark surface.

With my setup, for example, shining a light in the upper left corner of the image powers a dog food "allower" that uncovers a dog dish, and shining it in the lower right sounds a buzzer to signal dinnertime.

On the home computer, the video chat window runs full-screen, and cheap photosensors taped onto the screen's surface detect the changes in brightness when the flashlight spot image hits their locations. Each sensor then switches its device at home via a transistor or relay. Voilà!

By using the screen itself as a port, you bypass having to unpack USB or some other protocol, and you can add additional actuators by simply taping sensors to different parts of the screen.

This setup also keeps your home computer more secure than remote desktop access software such as VNC, unless Yahoo Messenger has some super-secret way of controlling your whole computer, which is unlikely.

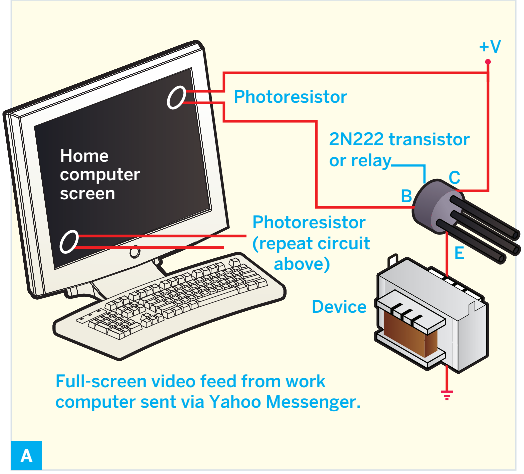
MATERIALS

FOR THE SETUP AT HOME:

Net-connected computer It's helpful if it has a webcam.
Soldering iron or wire-wrapping tool RadioShack part #64-2802 or #276-1570. Wrapping wire around component leads is less permanent than soldering, but it's OK for prototyping.
30-gauge wrapping wire RadioShack #278-503
Photoresistors, 5-pack RadioShack #276-1657
2N222 NPN transistors, 15-pack RadioShack #276-1617. Or use relays for higher-powered devices.
Solderless breadboard RadioShack #276-003
Devices, DC powered that you want to control remotely
DC power supplies with voltages that match your devices. You probably have some spare wall-warts from appliances you don't use anymore.
Electrical tape
Cardboard box (optional) but recommended, large enough to hold your computer screen

FOR THE REMOTE LOCATION:

Net-connected computer
Webcam that you can move and point (i.e. not built into the screen)
Dark, flat surface
Flashlight



A


B

Build Your Web Chat Home R/C

Time: 1 Hour **Complexity:** Easy

Set It Up

Install Yahoo Messenger (messenger.yahoo.com) on both your home and remote computers. Make 2 accounts under 2 matching names, one ending in "home" and the other ending in "work" (you'll need 2 email addresses for this; get free ones from Gmail or Hotmail or something). Separately log into each account from their respective machines, add them as friends for each other, and configure their Webcam preferences to "Allow everyone to view my webcam" and their Super Webcam preferences to "Start Super Webcam mode automatically."

For each device you want to control, solder or wire-wrap a long length of wire to each of the 2 leads of a photoresistor. Set up a power circuit for each device on a breadboard, following the schematic (Figure A). All of the power supplies should be plugged into a surge protector, like a power strip with a circuit breaker.

NOTE: You may need to insert an additional transistor/relay for higher-powered devices.

Then test whether the switching works for each device by covering and uncovering the photoresistors with your hand.

Use electrical tape (Figure B) to tape the photoresistors sensor-side down on the computer screen, spaced apart (Figure C, following page). Adjust the screen brightness to a level such that the devices switch off when the screen is black. With some circuits, I found that I had to put a piece of paper between the photoresistor and the screen to reduce the light. I recommend also putting the computer screen in a box to exclude non-screen light that could interfere with the sensor readings.

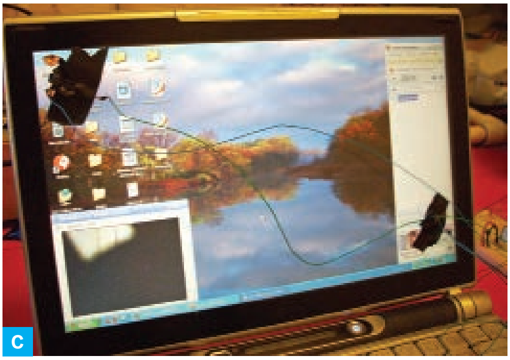
Set up your devices however they're going to work. It helps if your home computer has a webcam pointed at the devices, so you can remotely watch what's happening.

At your work computer, connect a webcam and set it up so that it looks at a dark, flat surface. I used a PVC stand that I'd already made for the camera and pointed it down onto a black T-shirt (Figure D).

Establish the Connection

On your work computer, run Yahoo Messenger. Next to your home username, select View My Webcam to open a webcam feed, then leave it running.

Illustration by Julian Honoré/p4rse.com; photography by Lee von Kraus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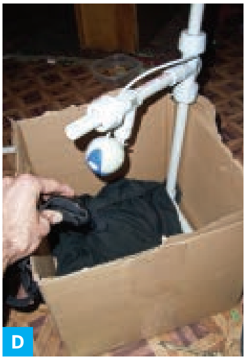
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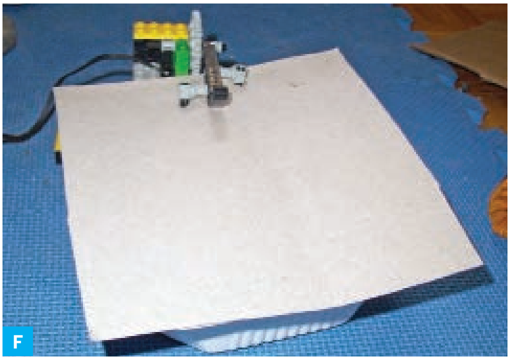
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On your home computer, click to view your work video feed. Change the window size so it fills your home computer's screen, or at least covers the area around all the sensors.

Back at work, shine a flashlight into the camera's field of view at different locations (Figure E) to activate the devices controlled by your home computer screen.

Recommendations

Test your system for a full day before you put it to use while you're away. Because it's based on analog sensors taped to a screen, there are little ways in which the "real world" will interfere with it. For instance, the photoresistors might fall off, or be triggered by changes in daylight coming through the windows.

If you want to control home devices wirelessly, I suggest an inexpensive, low-power infrared remote system like the Tiny-IR-II from Reynolds Electronics (rentron.com). Just replace the switches in the Tiny-IR-II encoder chip schematic with your photoresistor circuits' transistors, and use a decoder chip for each device.

Note that the system's range isn't great, and it uses infrared, like a TV remote, so all the devices should be in the same room as the transmitter.

With an IR remote system, it would also be good to dedicate an additional photoresistor circuit to a relay that all the other device circuits traverse. That way, you would have a "kill switch" that can shut the whole thing down if it starts acting wacky.

For more complex control, you can connect the sensor signals to a microcontroller. For my home system, I connected the transistor outputs to a PIC microcontroller and H-bridge motor controller IC that run a simple motorized dog food allower (Figures F and G) and a piezo buzzer. Both could be connected directly, as shown in Figure A, but I put a PIC in the loop to allow more complex outputs in the future.

I hope that this system helps people and also helps make some pets happier when they're at home alone.

For a video of the web chat R/C in action, visit makezine.com/22/home_rc.

Lee von Kraus lives with his dog, Sasha, in Brooklyn, N.Y. He is conducting research on creating language circuits in non-humans via cybernetic brain augmentation. leevonk.com

HOW TO MAKE A MOTION-SENSITIVE CAMERA TRAP

One man's journey to controlling a Nikon.

BY TOM IGOE

In any project, you learn a lot from the mistakes you make along the way. I recently set out to build a camera trap (hidden automated camera) for a wildlife observation project on which I'm collaborating. Here's the story of all the things I learned getting it to work.

Basically, I needed to make a motion-sensitive remote control for my Nikon camera. I was inspired by Matt Mets' Nikon Camera Intervalometer project (makezine.com/go/mets), which mimics the pocket remote trigger that comes with some Nikon cameras by running an infrared LED from an Arduino microcontroller.

Using Mets' NikonRemote library, you can take a picture with just 2 lines of code: one to initialize the output pin and one to actually snap the photo. Here's an example that takes a photo once per second:

```
#include <NikonRemote.h>
NikonRemote remote(12);      // IR LED on pin 12
void setup() {
}

void loop() {
  remote.Snap();
  delay(1000);
}
```

The code couldn't be any simpler. But naturally, the first time I tried it, it didn't work.

Photography by Tom Igoe

Build Your Motion-Fired Nikon Camera Remote

Time: **An Afternoon** **Complexity:** **Easy-Moderate**

Webcams Can See Infrared LEDs

My first step debugging was to make sure the infrared LED was working. A webcam will see a lit IR LED even if you can't, so I used the Photo Booth webcam application on my Mac to take a look. When I held my Arduino up to the camera, I saw the LED blink onscreen as it should, so I knew the code was controlling the LED (Figure A, following page). This meant either the bug was in the timing of the library code, or something was wrong with the camera. Checking the latter sounded much easier.

Read the Manual — Really! It Can Help!

I pointed Nikon's own mini remote at the camera and pressed the button. Nothing happened; time to read the manual. Sure enough, the Nikon DSLRs don't listen to the remote by default! A little fiddling with the camera settings, and the Arduino had control of the camera. A little reading can save hours of needless pain.

The Design

For the camera trap's motion detector, I connected a passive infrared (PIR) sensor from RadioShack to a digital input of the Arduino. The PIR sensor was very sensitive to even the slightest movement, and stayed on for several seconds after being triggered by motion. This is pretty typical for most PIR sensors I've encountered. So I wrote the code to trigger the camera only when the sensor changes from off to on, using a state change detection routine:

```
void checkMotionSensor() {
 // read the motion sensor:
 motionSensorReading =
  digitalRead(motionSensorPin);
 // if the sensor has changed since last reading:
 if (motionSensorReading != lastSensorReading) {
  //... and the sensor is HIGH, then take a picture:
  if (motionSensorReading == HIGH) {
   camera.Snap();
  }
 }
 // save the current state of the sensor
 // to compare the next reading to:
 lastSensorReading = motionSensorReading;
}
```

This handled motion detection. To let the user switch Sensor Mode on and off, and to easily see when it's on, I added a switch, an LED, and a bit of code to 2 more digital input/output pins in the Arduino.

An intervalometer would be handy too, so that I could trigger the camera at regular intervals to make time-lapse series. I added a potentiometer to set the rate, and 2 switches to control which function was active. As with the motion sensor, I threw in a power switch and an indicator LED to complete the physical interface for Intervalometer Mode.

A third visible-light LED indicates that the unit is on. Figures B and C show the trap's physical interface and its circuit on a breadboard; you can see a schematic at makezine.com/22/cameratrap.

Measure Thrice, Cut Once

I got a project box from RadioShack, because fabrication is not my strength. I tend to make a horrible mess when I get my hands on a saw or a Dremel. A friend of mine had a laser cutter in his shop, and was happy to do me a favor.

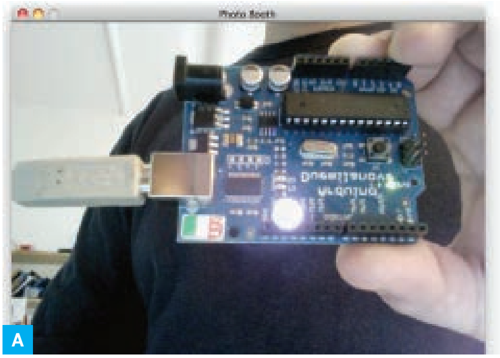
I measured my switches, potentiometer, sensor, and LEDs with a caliper, opened Adobe Illustrator, and drew up a plan. To make sure I had spaced things well, I printed the layout on paper, cut the holes out with a mat knife, and fitted the components. This turned out to be a wise move, because I hadn't left proper space between the potentiometer and the switches, and the IR sensor hole was too close to the box's screw mounts.

A few changes in Illustrator, another paper model, and we were ready to use the laser cutter. We did a test run on some scrap plastic first. More mistakes: this time my labels weren't readable. They'd printed

MATERIALS

Get everything you need for this project in the Project Pack #MKS1 at makershed.com.

Arduino Duemilanove #MKSP4 at makershed.com
PIR motion sensor
10kΩ resistors (2) and 4.7kΩ resistors (3)
3mm LEDs (3)
IR LED
Male headers, 0.1" spacing (15)
Female headers, 0.1" spacing (7)
Slide switches (3)
10kΩ potentiometer and matching knob
Project box
9V battery snap and 9V battery
PCB standoffs with #4-40 bolts (4)
#1-64 bolts, washers, and nuts (8)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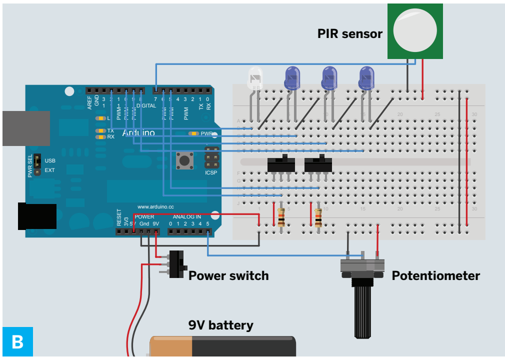


B

C

Figure C:

1. IR receiver
2. Lens
3. IR LED (on back of box) sends signal to camera to take photo.
4. PIR sensor detects motion for motion detector mode.
5. Motion detector mode switch
6. Knob (potentiometer) sets trigger rate for intervalometer mode.
7. Intervalometer mode switch
8. Power switch

fine on paper, but they didn't come out well on the cutter. Another round of adjustments, and we were ready to cut the actual project box top.

Despite all the careful preparation, I still messed up. We didn't delete the outline of the box top that we included when cutting the plastic scrap. So when we cut the actual box top, we shaved a bit off the edge (Figure D). I decided I'd live with this.

Design for Debugging Without Disassembly

I mounted the camera-triggering IR LED on the back of the box, so the PIR sensor and camera could face the same direction. The Arduino mounted to the inside back, and I decided to power it with a battery, and enclose it entirely. This turned out to be unwise, as it meant I had to take the box apart about 20 times to get to the USB port for debugging and reprogramming.

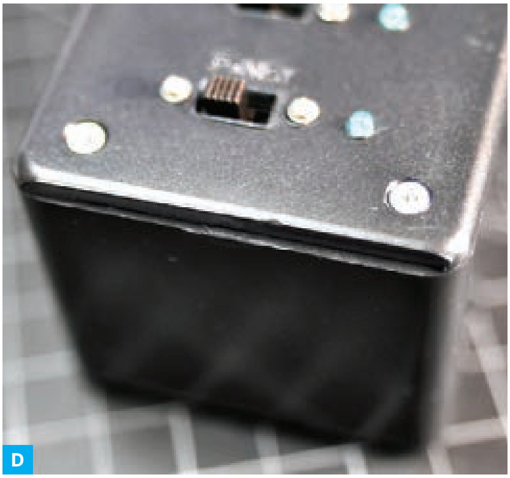
The components fit nicely in the box, but didn't leave much space for wiring. I ran a power and ground bus through all the components so I'd need only 2 wires to power the front. Connecting to the Arduino were 3 digital inputs (2 switches and the motion sensor), 3 digital outputs (the 3 visible LEDs), and an analog output (the potentiometer). I wired the power switch directly to the battery and put each group of connectors (digital in, digital out, analog in, power) on a separate row of male headers (Figure E) to plug into the Arduino, so they would be easy to plug and unplug. This turned out to be a good decision.

Test Your Inputs Before Writing the Actual Code

It's important to know what your inputs' readings are before you write the microcontroller program. A short program printing them out did the job:

```
void setup() {
  Serial.begin(9600);
}
```

Photography by Tom Igoe



D

```
void loop() {
  int potentiometer = analogRead(5);
  int motionSensorSwitch = digitalRead(6);
  int intervalometerSwitch = digitalRead(5);

  Serial.print(potentiometer);
  Serial.print("\t");
  Serial.print(motionSensorSwitch);
  Serial.print("\t");
  Serial.println(intervalometerSwitch);
}
```

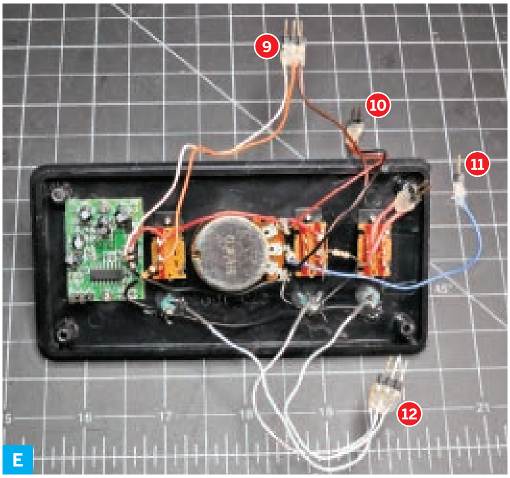
When I wired the potentiometer, I didn't pay attention to which side I wired to power and which to ground. So when I wrote a simple sketch to read the pot and print the values, I found that it read 1023 when the pot was all the way to the left, and 0 when it was all the way to the right: exactly the reverse of what I wanted. A little code adjustment solved this. I mapped the pot's input ranges from left to right (1,023 to 0) to a range of seconds (1 to 60) like so:

```
long interval = map(analogRead(potPin), 1023, 0, 1, 60);
```

Likewise, I had wired the switches backward. I wanted them on when they were near the corresponding LED and off when they weren't. The wiring made it hard to unmount them without resoldering, so I just reversed their logic in the code.

Test the Interface in Action

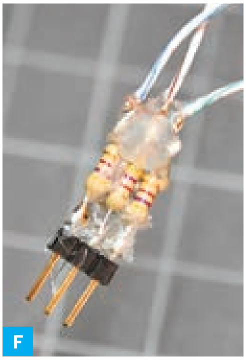
Finally, the box was built, the circuit worked, and the physical interface responded as it should. There was just one last consideration, the most important: all the elements of the display should be readable together. With the power off, the box



E

Figure E:

9 Digital inputs connector
10 Power connector
11 Potentiometer connector
12 LED connector



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looked very readable, but when the LEDs were on, they were so bright that they overwhelmed the engraved text.

A resistor in series with each LED (Figure F) dimmed each one down nicely, and the final box looks good and works well (Figure G).

+ For a breadboard diagram, schematic, code, and other resources, visit makezine.com/22/cameratrap.

Tom Igoe is an associate arts professor at the Interactive Telecommunications Program at New York University. He teaches about physical interaction design, and seeks a new improbable goal.

THE AUTOMATIC CHICKEN COOP

Build a henhouse motion detector that notifies you when your brood arrives safely in their coop each night.

BY ALAN GRAHAM

Growing up on a farm, there were many unpleasant tasks. Summers were filled with backbreaking labor, not to mention the daily chores of milking 80 or so cows and collecting the eggs and feeding the chickens.

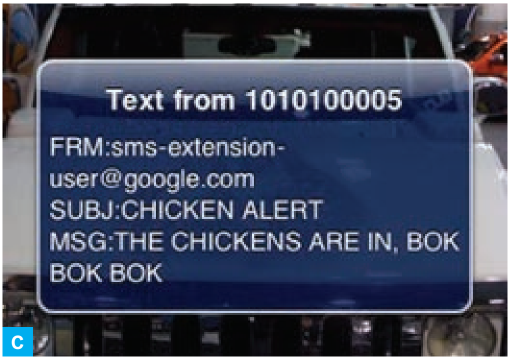
I now live in the city of Portland, Ore., and I've come to miss those farm days of 20 years ago. When I decided to get a couple of chickens, I was adamant that the work involved wouldn't seem like work. Gone are the days where I'd wake before dawn to get to the barn or prepare for a cold day chopping wood. These days it's all about waking with the sun.

One of the delightful aspects of chickens is that they're low-maintenance. As long as they can get out of the coop, grab a bite to eat, have access to fresh water, and retreat to a safe area at night, you basically have very little to do to keep them happy.

And seeing as I'm now a lazy, citified man, I wanted a solution that allowed for late mornings, weekend getaways, peace of mind, and avoiding any possible exposure to the elements, either to let the fowl out or collect the eggs. So with a few ideas garnered from around the web, and a few of my own, I cobbled together a henhouse that accomplishes a number of tasks without a single finger lifted, yet

Photography by Alan Graham

A



C

provides me with the knowledge that my lovely birds are always out at daybreak, but in at curfew.

I created an automated henhouse in my garage with an infrared motion detector, automatic lights, heater, and automated door. I know when they get out in the morning and I know when they come back in at night. Here's how I put it all together.

How My Henhouse Works

My system runs off a Mac Mini with home automation software, but what I'll describe here is a system you can build without a computer, using components from the online retailer smarthome.com.

My coop kicks on supplemental lights 2 hours before sunrise to increase egg laying in winter months (Figure A).

At 45 minutes after sunrise, the automated door rises (and I receive a verification email/text), allowing the girls to venture out into the yard for a little

B

D

free-range foraging (Figure B). To go in or out of the coop, the 2 chickens must cross a motion detector, which sends me a notification that they've left (another email/text). By counting the notifications, I also know when they're done laying their eggs in the morning. Then the supplemental lights and a waterproof heating pad both turn off. The door remains open throughout the day and the girls will sometimes wander back to grab a bite.

At sunset the supplemental light turns on in their coop, summoning them to return for the night. At this time the heating pad also turns on, giving them a little extra heat on cold winter nights. When the girls wander into their coop, an infrared motion detector registers their entrance and sends me an email/text notification (Figure C) so that I know, no matter where I might be, that the girls are safely in the building. Since they always wander in one after another, I get 2 notifications, one for each bird.

At 35 minutes after sunset, the chicken door closes (Figure D) and sends me a final confirmation via email/text that this has occurred. One hour later, the supplemental lights go off, and the girls are ready for their evening rest.

In the next section I'll describe a simpler system.

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F


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H

Simple Motion Detector and Lamp

Imagine that you're sitting in the warmth and comfort of your home, you want to lock your gals up for the night, but you aren't sure when they'll finally wander in. Put a motion detector in the coop and tie it to a table lamp in your house. When the hens arrive in their home, a lamp turns on in yours.

Smarthome's Wireless Insteon Motion Sensor (part #2420M, $35) is the most affordable way to detect hen arrival, however the trick with this type of motion detector is that since it covers a wide area (40' by 110° arc), you don't want it to constantly pick up motion from moving chickens and turn a light on and off all the time.

Instead you want to limit it to when the chicken crosses the threshold of the coop. I accomplished this by embedding the motion detector in a deep oatmeal can (Figure E), and pointing it across the threshold to create a focused beam in one precise location.

With the motion detector in place, the next thing you'll require is some type of notification. You might use Smarthome's LampLinc Dimmer Module (part #2457D2, $50, Figure F). It works as both a lamp controller and an RF receiver that can be linked directly to the motion detector.

After plugging a lamp into the LampLinc, you link the motion detector and LampLinc devices together by simply pressing a button on the back of the motion detector for a few seconds and then pressing a button on the LampLinc.

Once the two are linked, the detector will send an RF signal up to 150' to the LampLinc device whenever motion is detected. When the LampLinc receives the ON signal, it will turn the lamp on.

Now, the motion detector can and will send an OFF signal if it doesn't detect motion within 60 seconds. We don't actually want the LampLinc to turn off unless we manually turn it off.

To prevent this, simply unscrew the back panel of the motion detector, place the included jumper on both #4 jumper pins, and tap the Set button once (Figure G). Now the motion detector will send only the ON command.

But Wait, There's More

If you're willing to spend the money, there are a number of ways you can further automate your henhouse. Let's say when the hens come home at night and cross the motion detector, you want to trigger a heater or heating pad. Add a TimerLinc (part #2456S3T, $46) and an Insteon Appliance

Photography by Alan Graham (E, G, I, J)

I

K

On/Off Module (part #2856S3B, $30). When the hens come home the Appliance Module can turn on a small warming pad or other device, and then the TimerLinc can be set to turn off the device in the morning (Figures H and I).

Combine them with the Motorized Drape Controller (part #3142, $100), a sliding wooden door, some drape cord, and a counterweight, and you've got an automated chicken door that will open and close at specific times during the day, just like mine (Figure J).

Got predators? Combine the automated door with the Insteon Door Strike Kit (Figure K, part #51901, $138). Then set the TimerLinc to lock the henhouse door after it closes for the evening and unlock it in the morning before opening.

Live in an area where it freezes? Well, chickens need fresh water, not popsicles. Combine a heated water bowl with a TimerLinc and Appliance Module, and before your chickens are out the door in the morning, their water is thawed.

Want to receive a notification when you're away that your chickens are safe in their coop? Add the Insteon Telephone Alert Kit (part #73210, $155) and when Insteon events are triggered, say, the door has shut and locked, you'll get a phone call and hear a prerecorded message that the girls are good.

J

Coop Control via iPhone

There are a number of home automation software systems out there, for both PC and Mac. I use an app called Indigo (perceptiveautomation.com). One of the great aspects of this software is that it supports features like AppleScript, which allows me to do tricks such as sending text messages. For example, to receive a text message based on a conditional trigger, like chicken motion, Indigo performs the following AppleScript:

```
do shell script "curl -v -d gl='US' -d hl='en' -d
client='navclient-ffsms' -d c='1' -d mobile_user_
id='15555555' -d carrier='ATT' -d ec='' -d subject='CHICKEN
ALERT' -d text='THE CHICKENS ARE IN, BOK BOK BOK' -d
send_button='Send' http://www.google.com/sendtophone"
```

This AppleScript command has an embedded shell script in it that calls out to Google's free SMS service. I also get an email from Indigo, which has built-in support for SMTP email protocols. Indigo also has an iPhone app and can be controlled via a built-in web server.

With a dynamic DNS service and port forwarding, you can access and control your coop from anywhere in the world. Add a webcam, and you can be not only a lazy chicken farmer, but a remote one as well.

Residing in Portland, Ore., Alan Graham is the music and community liaison for Discovery's sites TreeHugger and Instrumental. In addition to chickens, his interests include home automation, cooking, and home automated cooking.
agraham999.com

TV-B-GONE HOODIE

Covertly turn off televisions with the tug of a zipper.

BY BECKY STERN

Whenever I bring my TV-B-Gone (a little wireless gadget that shuts off any TV) out to restaurants, I look suspicious using it. Mitch Altman, the device's creator, concealed his by putting it inside a hat (*see MAKE Volume 13, page 169*), but I rarely wear hats and I wanted a subtle solution.

So I bought a zippered hoodie sweatshirt from a thrift store and turned it into a wearable TV silencer. For the switch, I sewed paths of conductive thread to 2 little pads that are bridged by the metal zipper slider when it passes by, so all I have to do is zip the sweatshirt up or down to activate the TV turning-off action. It works great, and you can just unsnap the circuitry to convert it back into a normal sweatshirt for washing — or for avoiding trouble.

Build Your TV-B-Gone Hoodie

Time: 3 Hours **Complexity:** Moderate

1. Mount the circuit board onto the fabric swatch.

Assemble your TV-B-Gone according to the kit instructions, but omit the push-button switch, and mount the 4 infrared LEDs perpendicular to the printed circuit board.

Solder short wires to 2 of the 4 holes for the switch in the PCB. Pick the 2 that are visibly connected to the rest of the circuit. Strip the other ends and solder each to one half of a sewable snap. In the same way, attach 2 short wires to the board's power connections and snap halves; these will connect to the battery holder.

The fabric swatch will sandwich the circuit board to the hoodie and protect your skin from any pokey metal bits. Position the PCB in the middle of the swatch and use regular thread to stitch the 4 wired snaps along the swatch's corners and edge (Figure B).

Also stitch the wires and the board itself onto the swatch; I looped thread around component leads and through holes in the board, and reinforced the

LED leads with hot glue.

Finally, stitch 2 more snap halves onto the 2 empty corners, just for holding the other side of the swatch. Check that your TV-B-Gone still works properly by bridging the switch snaps with a piece of wire.

2. Attach the swatch and stitch the traces.

Position the TV-B-Gone swatch under the sweatshirt and use an awl to poke holes through the fabric for the 4 infrared LEDs (Figure C). Mark the positions of the 6 snaps on the inside of the sweatshirt.

Referring to the project schematic (Figure A), stitch conductive thread traces from the 2 switch snap positions to the edge of the zipper, making sure they never cross. Leave long tails of conductive thread at each end for hand-sewing the snaps and switch.

Insulated wire works better and is safer than conductive thread for supplying power, so solder 2 stranded wires to extend the length of the battery holder leads, and insulate the joints with heat-shrink tubing. Place the battery holder in the pocket (Figure D) and run the wires up to the power snap locations (Figure E). Tack the wires in place with regular thread.

Use the conductive thread to sew the 2 remaining switch snap halves in position inside the sweatshirt, matching their positions on the swatch (Figure E). Solder the 2 remaining power snap halves to the battery wires, then use regular thread to sew them into the sweatshirt.

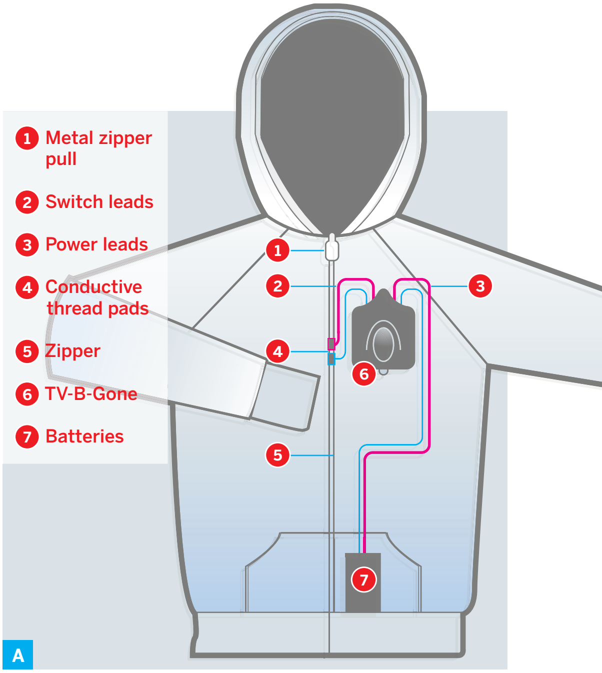
Photography by Becky Stern

MATERIALS

Super TV-B-Gone Kit item #MKAD4 from the Maker Shed (makershed.com), $22
Hooded sweatshirt with metal zipper slider, non-metal zipper teeth, and front pocket
Conductive thread $3 for 5yds from Sternlab (sternlab.org/store)
Stranded wire
Thread
Fabric swatch, about 2"×3"
Sewable metal snaps (6–8)
Heat-shrink tubing

TOOLS

Sewing needle and pins
Soldering iron and solder
Hot glue gun and glue
Awl
Scissors
Sandpaper
Sewing machine (optional)



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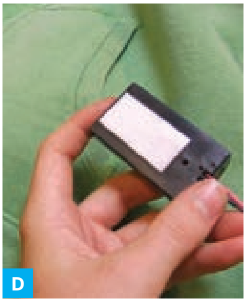
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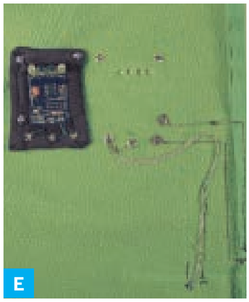
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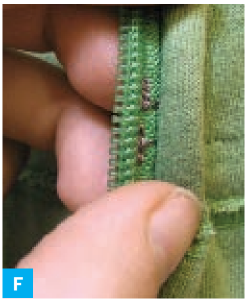
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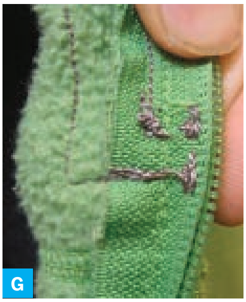
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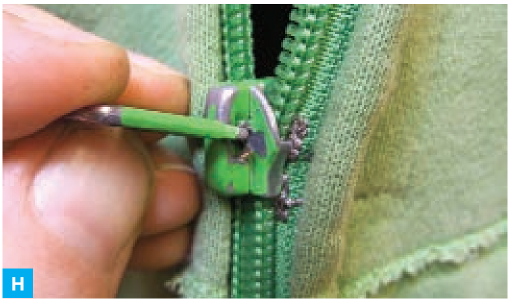
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Illustration by Julian Honoré/p4rse.com

Finally, use regular thread to sew the last 2 unconnected snap halves at the other end of the swatch.

3. Stitch the zipper switch.

Thread your needle with the conductive thread tails near the zipper, one at a time. Stitch 2 little pads right next to the zipper, close enough to each other to be bridged by the zipper slider (Figures F and G). Sand any paint off the metal zipper slider anywhere it will come into contact with the thread (Figure H).

Power on, and turn off some TVs!

Your TV-B-Gone hoodie is machine washable; just unsnap the circuit and remove the batteries beforehand, and let it dry completely before replacing them. You could even make the battery pack removable, by connecting it with metal snaps, too.

Becky Stern (sternlab.org) is associate editor for Make: Online (makezine.com) and CRAFT (craftzine.com).

HACKING R/C POWER OUTLETS

Inexpensive wireless home automation.

BY ANDREW WEDGBURY

Switching plug-in appliances from your computer or microcontroller isn't difficult in theory, but doing it without turning your home into a potential deathtrap can be tricky. The safer way is to rely on remote control rather than wiring directly.

Hack Your R/C Power Outlet

Time: **A Weekend** **Complexity:** **Medium**

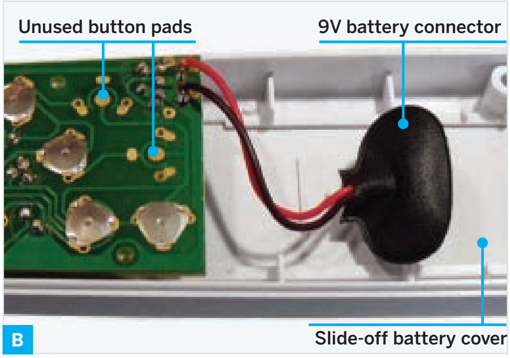
Here's how I reverse-engineered and modified an inexpensive R/C power outlet switching system so that it can control a practically unlimited number of AC-powered devices wirelessly from a computer. This flexible setup lets me switch appliances on and off via the internet and run programs that switch them automatically at certain times of the day.

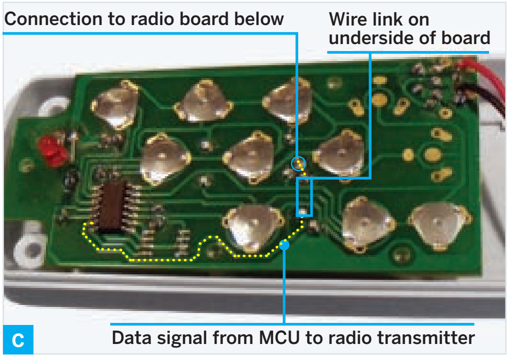
I had the idea for this project after buying a set of remote controlled power outlets from my local electronics store. Quite a few of these systems are available; they use radio frequencies, so you don't need line-of-sight like you would with IR remote systems, and some are even housed in waterproof casings for installing outside. They all work on the same principle: you plug an appliance through the R/C outlet unit into a regular power outlet, and then the remote lets you switch power to the appliance on and off.

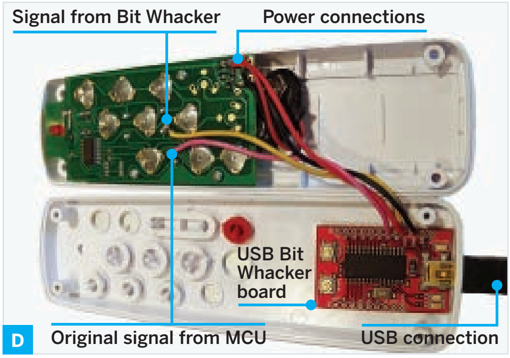
The set I bought (Figure A) has 3 outlet units and a remote control with On/Off buttons for each outlet, plus a master button pair that switches all outlets at once. You assign the buttons to the remote by pressing a Learn button on the outlet and then pressing the On button on the remote that you want to associate with it. If you wish, you can train multiple outlets to respond to the same button pair.

I was impressed by this system and was keen to expand it to control more than just 3 appliances. The instructions didn't mention whether multiple

Photography by Andrew Wedgbury







MATERIALS

R/C power outlet system I used a Maplin N19GN, which works for mains in the United Kingdom, and my code is tailored to its wireless protocol. You'll want to use a system with the appropriate power connectors and ratings for your country.

USB Bit Whacker microcontroller board part #DEV-00762 from SparkFun Electronics (sparkfun.com)

Insulated hookup wire

Wire cutters/strippers

Soldering supplies, and a screwdriver

PC computer with USB cable

sets would work without interference, but I noticed that if you left the remote's battery disconnected for a while, you had to retrain all the outlet units.

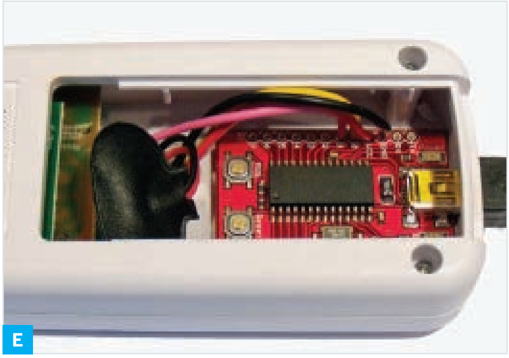
The only explanation I could think of for this was that the remote generates a new unique identifier when it powers up, which the outlet units store during the learning process. If so, this was a good sign, as it suggested that you could co-locate 2 or more sets (and other similar devices), provided that their remotes used different identifiers.

So far so good, except that you'd still need a separate remote for every 3 units, which would get out of hand if you wanted to control a lot of devices. To find better alternatives, I opened up the remote control unit. The main circuit board housed button pads, an Elan EM78P153SNJ microcontroller (MCU), a 5V regulator, and an LED (Figures B and C); underneath it sat another board with the radio transmitter circuit and antenna.

There was enough room inside the remote to hold a small microcontroller board. A microcontroller wired to the button contacts could then simulate button presses on the remote, and you could plug its USB interface into a computer to pass switching control over to the computer.

Also, the main board had unused pads for an extra pair of buttons, so it looked like you could easily wire the remote to control 4 devices instead of 3. By wiring into the remote like this, you don't need to modify the power outlet units at all; they remain safely intact with all their approvals (FCC, CE, UL, etc.).

But 4 devices per remote still isn't much, so I decided instead to try and intercept the data signals being sent from the remote's microcontroller to the radio transmitter circuit on the board underneath. If I could decode these signals, then I could also generate my own signals and control lots more devices, if the protocol allowed it.



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Splicing In

To decode and hopefully generate R/C signals, I used a USB Bit Whacker microcontroller from SparkFun Electronics. The remote's main board and the Bit Whacker both use 5V DC, and I knew I'd be running the Bit Whacker off USB power, so I connected power and ground between the Bit Whacker and the remote board, on the 5V side of its voltage regulator. This eliminated the need for the battery, by powering the remote over USB, and it also made room for the Bit Whacker, which fit neatly in the battery's place.

I needed to make 2 more connections to splice the Bit Whacker between the main board and the transmitter so it could intercept the signal. The yellow dotted line in Figure C (previous page) shows this data connection.

To intercept this connection, I simply severed a wire on the underside of the main board, soldered leads to each endpoint, and ran them to pins B0 and B1 on the Bit Whacker (Figure D). The pink wire feeds the remote's original button-press signals into the Bit Whacker's pin B1, and the yellow wire from pin B0 sends signals generated by the Bit Whacker to the transmitter circuit board.

I found that the Bit Whacker board could be glued inside the lid at the rear of the remote, where I cut out a rectangular hole for the USB port. With this modification, removing the battery compartment cover reveals the Bit Whacker (red board in Figure E).

Once the modifications to the remote were complete (Figure F), I turned to the software side of things. I would use the Bit Whacker to determine what the signals sent to the radio transmitter looked like, and then hopefully generate my own working signals by following the same protocol.

Cracking the Code

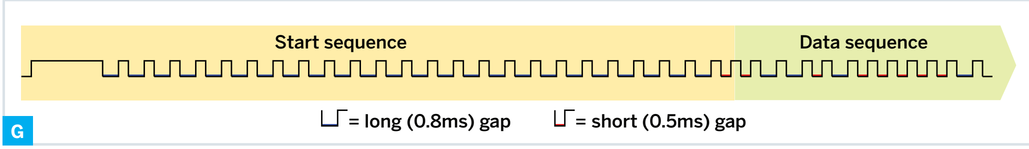
The Bit Whacker is a fantastically simple but versatile little board, consisting of a PIC18F2553 microcontroller plus a few supporting components: an oscillator, reset and program buttons, status LEDs, and a USB socket. It comes already programmed with firmware based on the Microchip USB framework that makes the device appear as a serial port (the firmware can also be updated over USB if desired).

You can control it by sending text-based commands using a terminal program such as Hyperterminal, or by writing your own program that talks to the serial port. A full set of commands is available to control the port pins and perform various other functions.

It was time to apply this functionality to eavesdrop on the remote. I considered sampling the signal to the remote's transmitter at regular intervals, but the PIC's memory was too small to store very many samples. Because the signal was probably digital (On or Off), I figured it would be more efficient to simply record the times between its state changes. To do this, I needed to make some modifications to the Bit Whacker's firmware, adding a new command that uses one of the PIC's timers to count the clock ticks, then write out and reset the value whenever input pin B1 changes. You can download this code at makezine.com/22/rcoutlets.

The Bit Whacker appears as a USB serial port. I connected to it with a terminal window, experimented with the remote buttons, and then analyzed the data that the Bit Whacker was putting out.

I found that each button press generates a long



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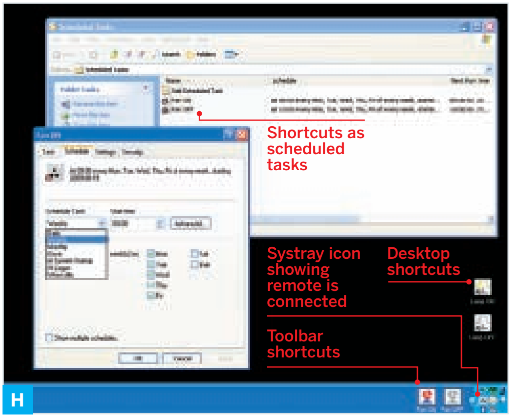

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start pulse followed by a fixed pattern of 25 pulses, which together act as a "get ready to receive" signal, followed by a variable pattern of 64 pulses encoding 8 bytes of data (Figure G). The start pulse is 3.6ms, and all subsequent pulses are 0.5ms. The gaps between pulses are either long (0.8ms), representing binary 0, or short (0.5ms), representing binary 1.

The way that the outlet unit's switching commands were encoded in these 8 bytes of data was not as simple as I had anticipated. Through further detective work, I found that the 8 bytes are decoded by the outlets into messages 4 bytes long.

Two of the 4 decoded bytes represent an identifier for the remote, which it picks randomly when it powers up and sends with each command (as I had guessed). Because this is a 16-bit value, it potentially allows for addressing up to 65,536 sets of outlet units. A third decoded byte conveys the power-switching command itself.

The remaining decoded byte is a counter value that increments with each command sent. This counter value obfuscated my code-breaking efforts, since it results in different data being sent every time the same button is pressed. But the outlet units don't actually check the counter value, and they respond to data encoded using the same counter value repeatedly.

The decoding scheme for the transmission was fairly simple. If you designate the 8-byte transmission as composed of bytes X1 to X4 followed by Y1 to Y4, you derive the decoded bytes Z1 to Z4 by subtracting each byte pairwise (shown below). Decoded byte Z1 is the counter, byte Z3 is the command, and bytes Z2 and Z4 make up the 2-byte identifier for the remote.

$$Z1 = X1 - Y1$$
$$Z2 = X2 - Y2$$
$$Z3 = X3 - Y3$$
$$Z4 = X4 - Y4$$

When I started programming the Bit Whacker to work the other way — encoding commands for transmission to the outlets — I found it was more complicated than simply picking byte values for X and Y that generated the right Zs. Instead, various relationships between the absolute values of the 8 encoded bytes had to be present in order for the outlet unit to accept the commands.

There's no serious encryption going on here, but all the internal arithmetic relationships act as a parity check, making it extremely unlikely for the outlet units to be triggered by random noise or interference from other systems.

The calculations below show how this encoding works. Note that all encoding and decoding operations are single byte (mod 256), which means that the value wraps around to 0 when incremented past 255.

$$Y1 = (4 * Z2) - (3 * Z1) + (2 * Z4) + Z3 + 97$$
$$X1 = Z1 + Y1$$
$$Y2 = Y1 + Z4 - 188$$
$$X2 = Z2 + Y2$$
$$X3 = X2 - 19$$
$$Y3 = X3 - Z3$$
$$X4 = X3 + Z4 - 104$$
$$Y4 = X4 - Z4$$

The decoded command byte, Z3, has several possible values. Most of them correspond to buttons on the remote control, but through testing I also found several other command values which the outlet units respond to. The most notable is `0x64`, which appears to affect only units that are currently off, switching them on for a brief moment and then off again. Here's a list of all the commands that

I was able to determine, as single byte values in 2-digit hexadecimal notation. There are commands to independently switch up to 4 units per remote, so given the number of possible identifiers, this allows 262,144 individual outlets to be controlled!

Command	Action
0x03	C off
0x04	C on
0x13	D off (generated by unused button pad on the remote)
0x14	D on (generated by unused button pad on the remote)
0x23	All off
0x24	All on
0x63	All off (no button)
0x64	Pulse all off units on momentarily, then off again (no button)
0xe3	A off
0xe4	A on
0xf3	B off
0xf4	B on

This information enabled me to encode and inject my own data to be transmitted to the outlet units. To accomplish this, I made some further modifications to the Bit Whacker firmware, so that it would generate waveforms comparable with those produced by the remote.

The Remote Outlet Control Application

The final part of the project was to write a computer application in C++ to control the units, as it wasn't very convenient having to enter commands into a serial console.

Rather than writing a fancy graphical application, I decided that a command-line program would be better. Firstly, it would be simpler, making it less prone to errors and easier to port (I wanted to run it on both Linux and Windows).

Secondly, I could easily create shortcut icons that controlled particular appliances by simply associating them with command-line program calls. Finally, I could automate the process in different ways, either by calling the program from a script or batch file in response to certain events, or else by triggering it at preset times from the Task Scheduler (on Windows) or a cron job (on Linux).

While developing my first version of the program, I found that if you called it twice in rapid succession, say, to switch multiple devices at the same time, the opening and closing of the USB port would sometimes fail. So I split the program into 2 separate processes: a server, which runs all the time in the background, holding the serial port open and managing the flow of commands; and a command-line client, which sends commands to the server.

I used TCP/IP sockets as the communication method, which lets the server and client run on different machines if desired.

You can download the application, Remote Outlet Control, at makezine.com/22/rcoutlets. Figure H (previous page) shows the application running on Windows. The electrical socket icon in the system tray indicates that the server process is running.

To create the toolbar at the bottom, I selected New Toolbar from the regular toolbar's right-click menu. Then I created the Lamp shortcuts on the desktop and the Fan shortcuts on the toolbar and entered the command-line program name, **outletctl**, and its required arguments (**device_ID [0-65535]**, **button [a, b, c, d, all]**, and **state [on, off]**) in the Target box. I also chose an appropriate icon using the Change Icon button. (I created all of the application's icons using Inkscape.)

For the scheduled tasks shown, I dragged the desired shortcuts into the Scheduled Tasks window, under Control Panel/Administrative Tools. This pane supports numerous scheduling options, but if it isn't flexible enough, you can also call the program from a batch file or scripting language of your choice (I'd recommend Perl).

There's a great deal of potential in these off-the-shelf remote outlet systems; their availability and relatively low cost makes them ideal for any electronic projects that need to switch plug-in appliances.

This project highlights just one way of using them, and I've tried to keep my modifications as general as possible so they're useful to others. Hopefully I've shown how easy it can be to interface with these systems, and how, by understanding a bit about how they work, you can make them work the way you want them to!

+ For the modified Bit Whacker firmware and computer applications, along with all source code, visit makezine.com/22/rcoutlets.

Andrew Wedgbury is a software engineer, keen electronics hobbyist, and big fan of open source software and hardware. He always has a few projects on the go, which he tries to document at sconemad.com.

REMOTE CONTROL STATE OF THE ART

Innovators and enthusiasts from remote realms tell us what's on their radars.

BY GARETH BRANWYN

We tapped industry leaders and hobbyists on the shoulder, and asked them a simple question: What are you most excited about in the realms of remote control and teleoperation right now?

Jim Bourke, owner of RCGroups (rcgroups.com), tireless advocate of all things R/C
I'm continually amazed by the dedication and engineering prowess of R/C modelers. Here are just a few cutting-edge areas of the hobby:

People are equipping model planes and helicopters with tilt and pan rigs and micro cameras, broadcasting **live first-person video (FPV)** to video goggles and head-tracking systems. This makes for the ultimate sense of realism in model aircraft flight.

R/C gear keeps getting smaller and cheaper. Rather than spending several hundreds on kits, a lot of economizing R/Cers are building planes out of cheap foam material, such as the blue insulation sold in home/hardware stores. These **"foamies"** fly great, cost only a few dollars for the basic airframe, and can be assembled in an evening.

The coolest thing in R/C helis is the teeny-tiny **micro helicopters**, many of which are designed and built by the hobbyists themselves. Since designing your own heli can be challenging, most people start with off-the-shelf models and customize from there. One popular model is the Blade, from E-flite (e-fliterc.com). Their new Blade mSR single-rotor is a bit challenging to fly, but more capable than others in its class.

I-Wei Huang, Crabfu Steamworks (crabfu.com), maker of steam-driven and other R/C vehicles
Micros, especially **micro flying machines**, are going mass market. Just a few years ago, there were no real planes and helis at the sub/ultra-micro scale that performed very well. Now there are many, and performance is truly impressive. Recent scaling down of **ultra-micro servos**, surface-mount electronics, and advances in LiPo (lithium-ion polymer)

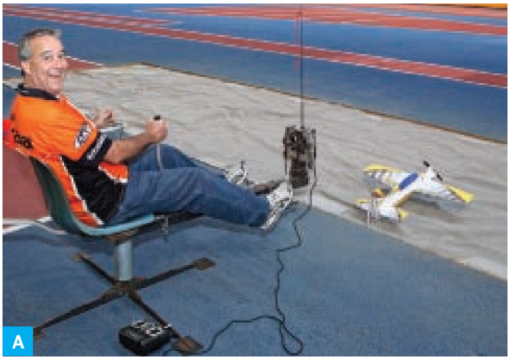


Fig. A: Mark Fadely, a model plane enthusiast and photographer who hangs out on the popular rcgroups.com forum, takes a seat in the Heli-Chair controller (with a "foamie" on the runway).

Photograph by Andy Ponocillo

batteries have opened up lots of new doors for R/C builders. And the learning curve is getting so much easier for beginners.

A few years ago, I got interested in **R/C crawlers**, R/C trucks that can climb over rough terrain. Back then, people were hacking differentials and modding shocks and springs to make these fast trucks go as slow as possible, to get the most articulation and torque, for climbing over boulders. There was a small community then "Frankensteining" projects, merging different trucks together. People were buying expensive vehicles just to use the parts they needed, and selling the rest to others within the community.

Today, there are many off-the-shelf crawlers to choose from. RC4WD (rc4wdstore.com) has turned this R/C hacking hobby into a successful business. Six years ago, the owners were using J-B Weld to lock differentials, and selling them on eBay. Today they have several locations, and sell their CNC-built crawlers all over the world. [*See our review in Toolbox, page 150.*]

Jamie Burke, host of the *All Things That Fly* and *Inside Heli* podcasts (allthingsthatfly.com)
Thinking of how the R/C industry has evolved, it's


B


C

Fig. B: The popular Traxxas Summit crawler, complete with headlights for night driving.
Fig. C: The amazingly small E-flite Blade mSR "ultra-micro" helicopter. Next stop: R/C flyers the size of butterflies.

Photography courtesy of Traxxas (B) and by I-Wei Huang (C)

amazing to see what's come about and what's on the horizon. Moore's Law is definitely at work in the R/C world. As electronics get smaller, faster, cheaper, better, we're about to see the explosion of **ultra-micro flying machines** (think: flying a butterfly).

If you consider what we've seen in the last year and a half, with the introduction of **ParkZone planes** (that can fly in a small outdoor area) and Horizon Hobby's **Bind-N-Fly technology** (where the plane is "bound" to a specific digital spread-spectrum radio transmitter), the next 18 months is going to be insanely cheap, small, stable, and exciting.

Akihide Hirata, Starfleet Yokosuka Dry Docks (hm-arts.com/starfleet_ydd), a leading light in the Japanese aqua modelers scene
I believe that **the underwater environment** is the place where everyone can experience something similar to piloting a ship through space. The underwater world has granted me my dream of flying spaceships, and I believe that the "final frontier" (or at least the next one) for R/C is underwater.

Jason Winters, CEO, ioBridge (iobridge.com), makers of modules for net-controlling devices
The concept of "remote control" has changed greatly since I was a kid in the 80s. Back then, a remote was limited to changing channels on a TV, or steering a toy car or plane. In both cases, range was limited and the remote itself was specifically designed for each application. Today, by **using the internet to send control signals**, range is no longer limited by transmission power. Any location with a net connection can be a potential command point. Likewise, a web browser can replace a physical remote control and offer unlimited flexibility. With its portability and net access, **the smartphone** is the remote control of the future.

Some applications for ioBridge products include:

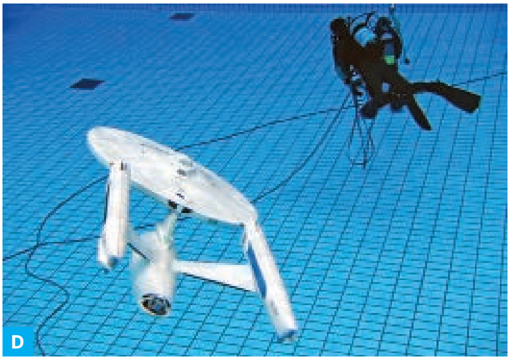
» Solar hot water monitoring (ejesolar.com) Eric Edwards built a system for monitoring his home's solar-powered water heating system from his mobile phone.

» LaserPup (laserpup.com) Joe's dog Skyler liked playing the laser pointer chasing game and Joe wanted to interact with Skyler while he was away from home. So he built a device with servos and a laser pointer that mounts on the ceiling. A little JavaScript ties it all together, and he's able to play laser chase with Skyler, over his iPhone, from virtually anywhere.

» RFID Phone Dialer (makezine.com/go/rfidphone) Stephen Myers realized that the elderly have difficulty with the small buttons and menus of modern phones. So he created an automatic phone dialer, triggered by RFID tags attached to pictures. Move the picture of the person you want to call past the device, and ioBridge directs Google Voice to place the call.

Chris Anderson, editor-in-chief of *Wired* and creator of DIY Drones (diydrones.com)
The main R/C technologies that interest us are better **ways to bridge the R/C and computer worlds**. As much as we love what the digital revolution has done for R/C gear, with collision-free spread-spectrum and programmable radios, at the end of the day, it's still analog-in (fingers on sticks) and analog-out (pulse-width modulation [PWM] signals to servomotors).

Right now, it's hard to beat the decades of innovation that have gone into modern R/C, which is both



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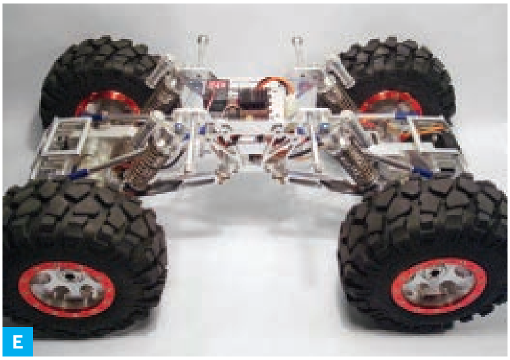


E

F

Fig. D: Akihide Hirata's *USS Enterprise* goes where no starship has gone before: your swimming pool. Fig. E: Crawler kit from RC4WD. What began as a hobby "Frankensteining" truck kits is now a full-time business CNC-milling kit components. Fig. F: Drive a real car with an iPhone? Douglas Farrell does.

powerful and reliable, so I think it'll remain at the core of remote control tech for years to come. The newest digital equipment, such as the Hitec Aurora, even has a **back channel for telemetry** and other aircraft information, so there's lots of development still happening.

But ultimately, computers will win and I expect the robotics world, including UAVs, will eventually come up with cheap and easy-to-use radio systems that are computer-driven from end to end. The machines will do the driving, while we just watch. Fingers on sticks will become the weak link in the chain.

Francesco Fondi, publisher of *Xtreme RC Cars* Italian edition (rc411.com, hobbymedia.it)
R/C hobby culture is deeply connected to maker culture, as R/Cers love to build, unbuild, and modify models as they see fit. For the average consumer, R/C is a way that they discover their mechanical and electronic creativity; it's their way into making!

Right now, the **quality of R/C kits** is so incredibly high, while at the same time, it's cheaper than ever.

In the last few years, the new trend has been **Ready-To-Run (RTR) cars** and **Ready-To-Fly (RTF) planes**; models are sold built and ready to go right out of the box. Traditionally, model cars and planes are sold as kits, and R/C purists hate RTRs/RTFs. I see these products as just a way to get more people involved in the hobby. R/C models need maintenance, and beg for improvements, so sooner or later, nearly everyone ends up "under the hood" and becomes a maker.

One of the most innovative new R/C cars is the **Traxxas Summit** (traxxas.com), which can be used as a monster truck or a rock crawler.

Will Schoettler, Waterloo Labs, DIY engineers and rogue scientists (waterloolabs.com)
Remote control and teleoperation technology permeates our lives: it's in home networks, electronic controllers, even household devices. You can take a cellphone and control just about anything from it.

In our project **Driving a Car with an iPhone**, we remotely controlled a fully-functional Oldsmobile Delta 88 with an iPhone. All it took was sending commands from the phone over wi-fi to a **CompactRIO controller** (ni.com/compactrio), which was programmed to control some motors.

That same CompactRIO could be programmed to cook your breakfast. The iPhone could send instructions to a stereo equalizer. The possibilities are endless. The technology has become available everywhere, and with just a little knowledge of programming, it's now accessible to anyone.

+ More online at makezine.com/22/rcroundup.

Gareth Branwyn is editor-in-chief of Make: Online.

Photography by Akihide Hirata (D), Rob Shouldis (E), and Will Schoettler (F)

1+2+3

Sculpting Circuits

By Samuel Johnson and AnnMarie Thomas

Making play-dough creatures is fun, but making them with light-up eyes and moving parts is even more enjoyable. We thought it would be better still if we could make the circuitry out of the dough itself!

Most play dough is already conductive, but we needed a way to insulate the conductive dough. We came up with a sugar-based dough that works well as an insulator. It's pliable and resistant to blending with the conductive dough.

Rainy day and fidgety kids? Whip up both types of dough, gather some LEDs and batteries, and create your own menagerie of squishy circuit creations. Add a motor or two for sculptures with moving parts. Feeling adventurous? Play with the salt content of the recipes to vary their conductivity.

YOU WILL NEED

For conductive dough:
- **1c water**
- **1½c flour**
- **¼c salt**
- **3Tbsp cream of tartar**
- **1Tbsp vegetable oil**
- **Food coloring (optional)**

For insulating dough:
- **1½c flour**
- **½c sugar**
- **3Tbsp vegetable oil**
- **1tsp granulated alum**
- **½c distilled or deionized water (check lab supply stores)**

Assorted LEDs
4 AA batteries in a battery holder
Low-current DC motors

1. Make the conductive dough.

Reserve ½c flour, and mix the remaining ingredients in a medium-sized pot. Cook over medium heat, stirring continuously. The mixture will begin to boil and get chunky. Keep stirring until a ball forms in the center of the pot. Once a ball forms, turn off the heat and remove the dough to a lightly floured surface.

CAUTION: The dough will be very hot! Flatten it and let it cool for a couple of minutes before handling.

Slowly knead the remaining flour into the ball until you've reached the desired consistency.

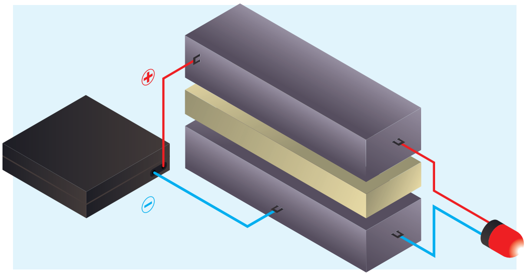
Store dough in an airtight container or plastic bag. In the bag, water from the dough will create condensation. This is normal. Just knead the dough after removing it from the bag, and it will be as good as new. Stored properly, it should keep for several weeks. If it dries out, just add a little more deionized water and knead it with some flour.

2. Make the insulating dough.

Mix the dry ingredients and oil in a pot or large bowl. Mix in 1Tbsp of deionized water and knead; repeat until the mixture becomes moist and dough-like.

Remove the mixture from the pot or bowl, and slowly knead flour into it until it attains a firm consistency. You should use almost the entire ½c of flour.

NOTE: You probably won't need more than ¼c of deionized water, but have ½c ready just in case.



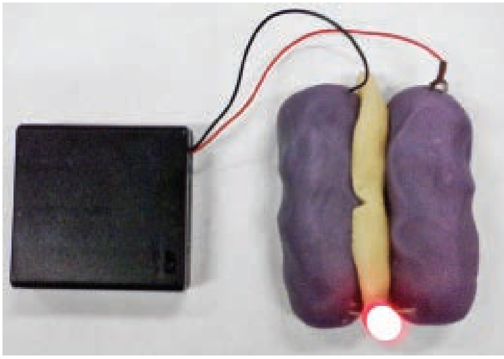


Illustration by Julian Honoré/p4rse.com; photograph by Samuel Johnson

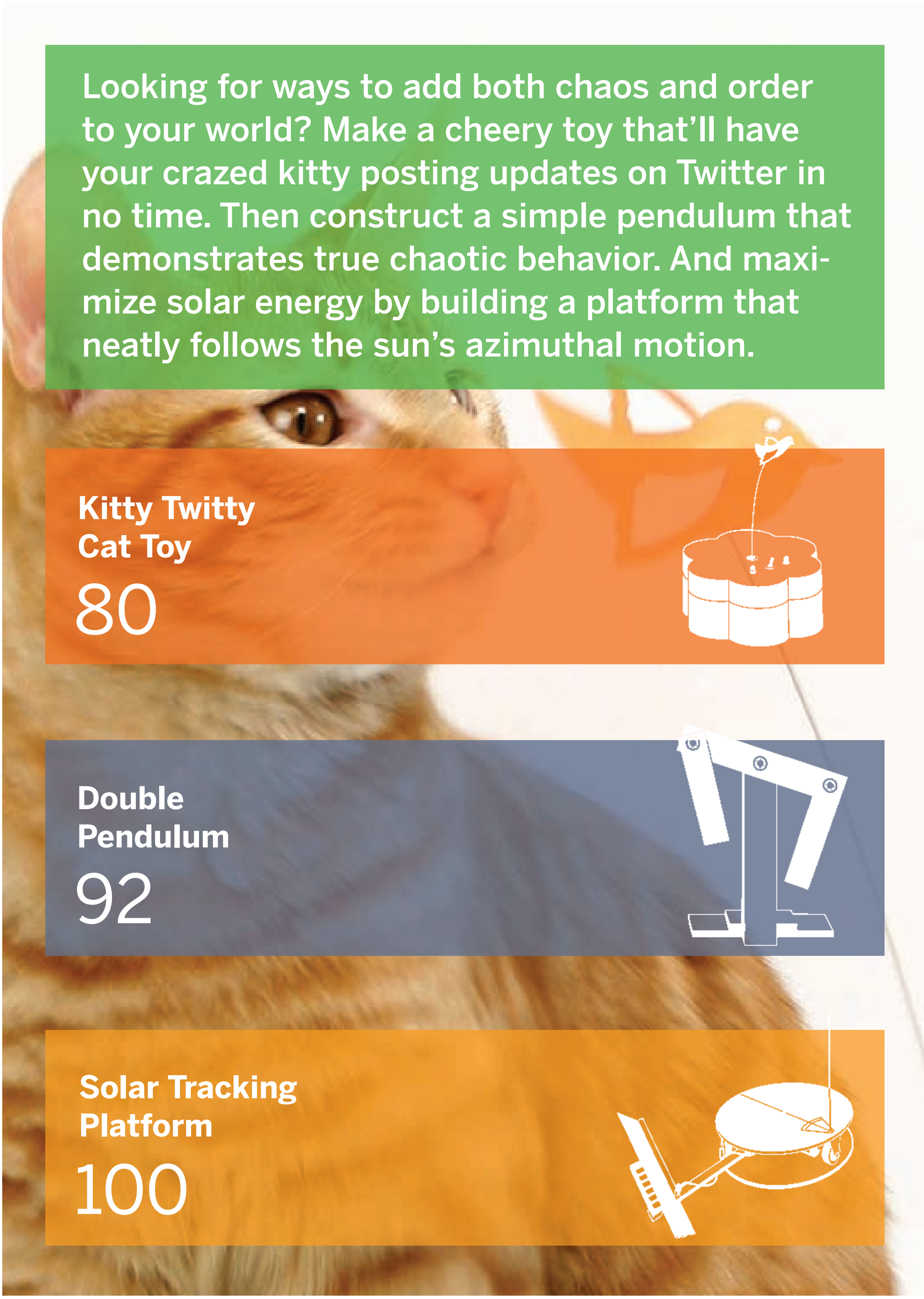
3. Make squishy circuits.

Insert the 2 leads from the battery pack into 2 pieces of conductive dough, separated by a lump of insulating dough (we recommend using food coloring to differentiate the doughs).

Insert an LED so its anode (long lead) is in the positive battery lump, and its cathode (short lead) is in the negative battery lump. It will light up!

Samuel Johnson is from Blaine, Minn., and is an engineering student at the University of St. Thomas. AnnMarie Thomas is an engineering professor at the same university, and co-director of the Center for Pre-Collegiate Engineering Education.

Make: Projects



Looking for ways to add both chaos and order to your world? Make a cheery toy that'll have your crazed kitty posting updates on Twitter in no time. Then construct a simple pendulum that demonstrates true chaotic behavior. And maximize solar energy by building a platform that neatly follows the sun's azimuthal motion.

Kitty Twitty Cat Toy

80

Double Pendulum

92

Solar Tracking Platform

100

Photograph by Marc de Vinck

KITTY TWITTY CAT TOY

By Marc de Vinck

I CAN HAS TWITTER?

Make a cheery cat toy that sends tweets, and let your cat join the millions of other Twitter-critters who update the world regularly with their activities.

About 2 months ago, after years of begging and pleading from my family, I reluctantly agreed to get another cat from the local shelter. We already have a menagerie of beasts that share our home, but for some reason they felt we needed another.

I admit, I do like our new addition to the family. Chester is a spunky little stray who's always looking for fun. Even if it means knocking a few things off my desk as I write this article. The only problem is, when my wife goes in to work, she misses her new cat and always wants to know his whereabouts.

She used to ask me for updates, but after a while I realized that I needed to make something that would take me out of the loop, and let the cat communicate with my wife directly via twitter.com. I needed a Twittering cat toy. And that's how Kitty Twitty came to fruition, after some basic soldering and crafting with just a few parts.

Photography by Marc de Vinck

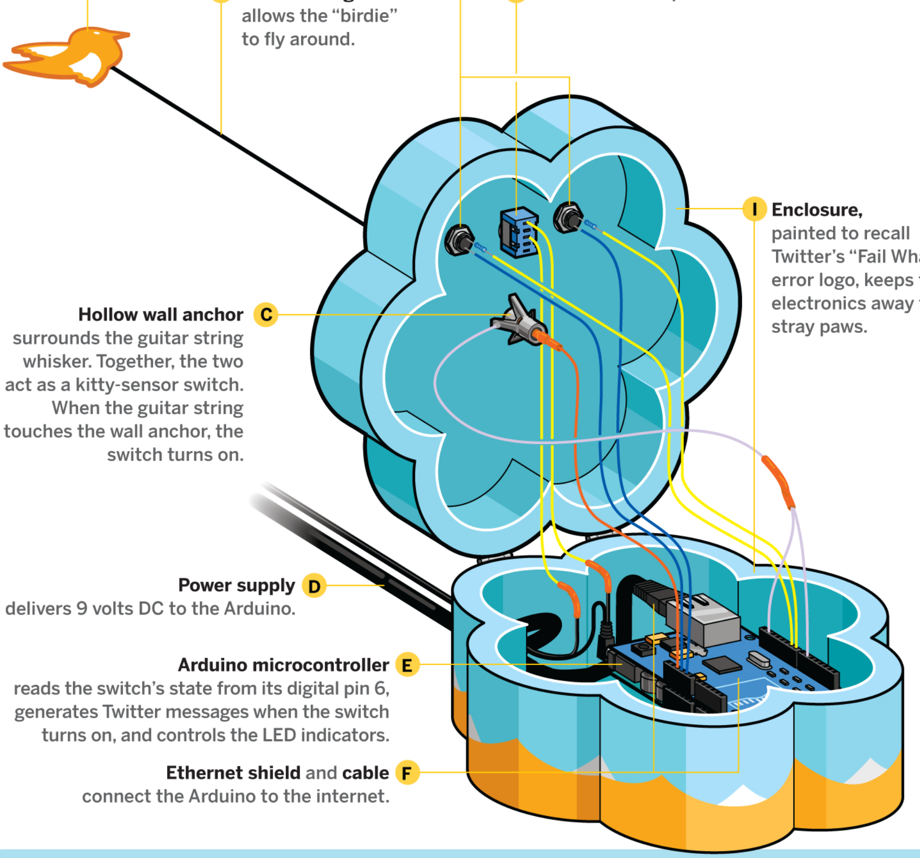
Set up: p.83 **Make it: p.84** **Use it: p.91**

Marc de Vinck moonlights as an artist creating interactive sculpture from his studio in the Northeast. He is a member of the MAKE Advisory Board, a contributing writer for MAKE, and the product curator for the Maker Shed.

Kitty Twitty: HOW IT WORKS

Kitty Twitty senses and Twitters felinogenic perturbations to its cat-attracting whisker.

BONUS! Papercraft bird costumes for your Kitty Twitty! makezine.com/22/kittytwitty



A Paper bird makes kitty go crazy!

B Guitar string "whisker" allows the "birdie" to fly around.

C Hollow wall anchor surrounds the guitar string whisker. Together, the two act as a kitty-sensor switch. When the guitar string touches the wall anchor, the switch turns on.

D Power supply delivers 9 volts DC to the Arduino.

E Arduino microcontroller reads the switch's state from its digital pin 6, generates Twitter messages when the switch turns on, and controls the LED indicators.

F Ethernet shield and **cable** connect the Arduino to the internet.

G LEDs indicate power and network connectivity.

H Switch controls power to the Arduino.

I Enclosure, painted to recall Twitter's "Fail Whale" error logo, keeps the electronics away from stray paws.

Software

The Arduino code generates semi-random Twitter messages of the form, *Chester loves Kitty Twitty! Meow!* or *Monster cat attacked Kitty Twitty! Mwaha-haha!*, where the subject refers to the cat, the direct object is always "Kitty Twitty," and the tweet ends with an exclamation from the cat's point of view.

The sentences are varied because Twitter filters out identical, repeated tweets. Generating a unique sentence each time circumvents this block (and is more fun).

Another limit imposed by Twitter is a maximum of 150 tweets per hour (tph). So the code adds a 30-second delay after each send, effectively keeping Kitty Twitty's tweetrate under 120tph.

Illustration by Rob Nance

SET UP.

MATERIALS

[A] Arduino Duemilanove item #MKSP4 from the Maker Shed (makershed.com)

[B] Arduino Ethernet Shield Maker Shed #MKSP7

[C] 9-volt power supply Maker Shed #MKSF3. Or use a 9V battery with a center-positive 5.5mm×2.1mm barrel connector, especially if your cat chews on wires.

[D] Enclosure This can be almost anything, as long as the Arduino and Ethernet Shield fit inside. Also, since your cat will be playing with it, no glass or toxic paints, and the heavier the better. I used a $6 wooden box from a local craft store.

From an electronics supplier, such as Digi-Key, Mouser, or RadioShack:

[E] LEDs: green (1) and blue (1)

[F] Resistor, 10kΩ

[G] Resistors, 220Ω (2) or other value matched to lighting your LEDs with 5V DC

[H] LED holders (2)

[I] SPST switch I used a sub-mini toggle, RadioShack part #275-0612.

[J] Ethernet cable

[K] Solid-core wire, 22 gauge, 2'–3', various colors

[L] Solder, rosin-core

[M] Heat-shrink tubing, ⅛" diameter

From a craft store:

[N] Craft glue, nontoxic

[O] Paint, nontoxic

[P] Paper, various colors

[Q] Glue stick

[R] Nontoxic sealer (optional)

[S] Guitar E string or similar steel wire

[T] Hollow wall anchor, medium duty, metal #6-32×1½" or similar, from a hardware store

TOOLS

[U] Soldering iron

[V] MAKE: Warranty Voider Leatherman "Squirt" E4 #MKWVE4 from the Maker Shed. Or you can use standard cutting pliers and needlenose pliers.

[W] Paintbrushes

[X] Fume extractor (optional) but highly recommended, for your respiratory health when soldering. To make your own, see MAKE Volume 19, page 123.

[NOT SHOWN]

Computer running Arduino software free download at arduino.cc

USB A-B cable for programming the Arduino. Borrow one from your printer.

Drill and drill bits: ⅛", ⅝", ½" spade My LED holders and switch needed ⅝" holes; yours may vary.

Phillips screwdriver

Pencil and eraser

Scissors

Binder clips, various sizes (optional)

MAKE IT.

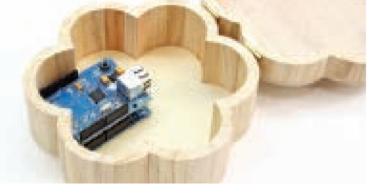
BUILD YOUR KITTY TWITTY

START **Time:** 1 Day **Complexity:** Moderate

1. DRILL AND PAINT THE ENCLOSURE

Chester doesn't get too aggressive with the Kitty Twitty, but if he ever does, I'll add some weight to the enclosure to help keep it upright.

1a. Decide where to drill the hole for the power and Ethernet cables. Attach the Ethernet shield on top of the Arduino and place them in the box to see where they fit best. Mark the location of the hole with a pencil on the outside of the box.



1b. Use a ½" spade bit to drill the hole, and go slow to minimize splintering. Once the hole is drilled, give it a quick test-fit. Does it fit? Yes? Good!

1c. Mark the 4 holes where you want to mount the 2 LED holders, the power switch, and the hollow wall anchor. The wall anchor should be in the center.

1d. Drill small pilot holes at each location (⅛" should work) and then drill out the holes to fit the components.

1e. Test-fit the components, but don't permanently attach anything yet.

1f. Decorate! I marked out my design in pencil and then painted it with kitty-safe nontoxic paint. Don't forget to paint the inside; you'll want to show your friends how it works, and having a painted inside looks so much cooler!

1g. After the paint dries, attach the LED holders and the switch to their respective holes. A few nuts and washers, and it's done.

1h. Finally, attach the hollow wall anchor. Screw it in slowly to avoid damaging the wood, and don't overtighten. The anchor will fold up on itself and its "legs" will secure it against the inside of the box, but they shouldn't dig into the surface. Once the anchor is in place, remove the screw.

2. MAKE THE SENSOR

2a. Cut the guitar string to about 10"–12", keeping the lug end (with the little brass barrel). The lug will prevent the wire from being pulled out by an aggressive kitty. If you're using plain steel wire, tie a knot instead.

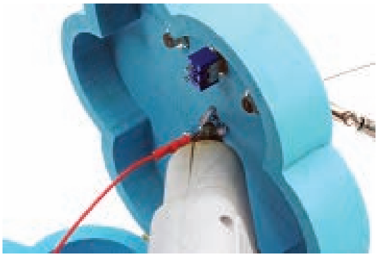
2b. Use small pliers to curl the cut end around, so it will attach to the toy more easily and won't expose the cat to being poked with a sharp wire.

2c. To electrically insulate the guitar wire from the wall anchor, cut two ½"-long pieces of ⅛" heat-shrink tubing, then slip and shrink them one by one over the wire at the lug end.

2d. Solder a 6" length of insulated solid-core wire (I chose red) to the brass lug grommet, extended away from the guitar string, and encase the entire connection in another piece of heat-shrink.

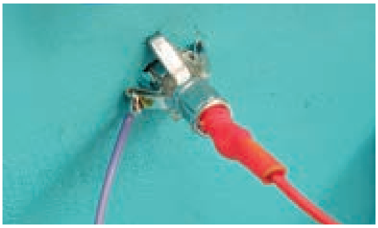
2e. Thread the guitar string through the underside of the hollow wall anchor and screw in the wad of heat-shrink. It's OK if it's a tight fit; my heat-shrink even twisted a bit, which made for a nice fit. But make sure the wires and lug do not make any metal-to-metal contact with the anchor.

2f. While keeping the guitar string centered (I used a "third hand" but you could have a friend hold it steady), apply some hot glue into the core of the hollow wall anchor around the string. You don't want to fill the entire cavity, just a bit around the bottom to further insulate the guitar string and keep it straight and secure. If you add too much hot glue, the wire won't be able to flex enough to touch the top of the anchor, so err on the side of caution and use only a dab or two.



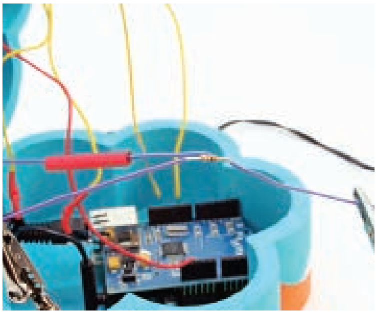
2g. Feed the Ethernet and power cables through the hole you drilled in Step 1b. Tie a simple knot to keep them from being pulled out of the box. Position the Arduino boards in the box, plug in both cables, and also plug the red wire from the guitar string into its 5V header socket.

2h. On the lid of the box, solder a 3"–4" piece of wire to one of the anchor's legs. Using a different color wire (purple here) will help. The anchor draws a lot of heat away, so you'll need to heat it with the soldering iron for a while, or else the solder will bead up and you won't get a good joint.



2i. Now we'll split the connection from the hollow wall anchor so that one wire goes to an Arduino ground pin (GND) through a 10kΩ resistor, and the other wire connects to its digital I/O pin 6. Doing this pulls pin 6 to ground, so that it reads LOW unless contact is made by the sensor.

Strip, twist, and solder a wire to the end of the anchor wire, along with one end of the pull-down resistor. Then solder a third wire to the other end of the resistor, and insulate the entire junction with a long piece of heat-shrink. Make sure you can identify which lead runs to the resistor and which goes directly to the anchor.

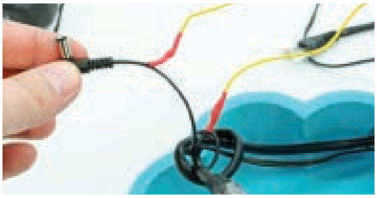


3. WIRE THE SWITCH AND LEDS

3a. Unplug the power supply cord at both ends, and then cut and strip one of its wires about 2" from the barrel plug end.

3b. Solder a piece of wire to each end of the cut wire, and seal both connections with some heat-shrink tubing.

TIP: Electrical tape will work too, but I find that using heat-shrink makes for a more permanent solution.



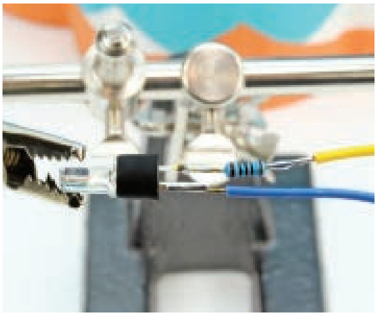
3c. Solder the free ends of the wires you just attached to the 2 terminals of your switch. No need to worry about the polarity; either way works.

3d. If you're using LED holders, remove their rubber grommets and insert an LED into each. Make sure you know which color LED is which.

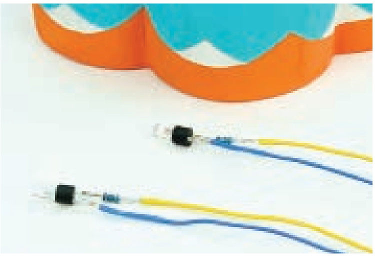
TIP: If your LED is clear, you can verify its color by pressing its leads around a 3V coin-cell battery (CR2032), longer lead on the positive (+) side of the battery and shorter on the negative (–).

3e. For each LED, solder a 220Ω resistor (or similar value) between the positive (longer) lead and a 3"–4" length of wire. The resistor limits the amount of current that flows through the LED, so that it won't burn out. Solder a 3"–4" wire of a different color to each negative lead. I used yellow for positive and blue for negative, but red and black are traditional.

NOTE: If your enclosure is shallow, you may need to trim the LED leads before soldering so that the lid will close. Cut them at an angle to retain the different lengths that indicate (+/–) polarity.

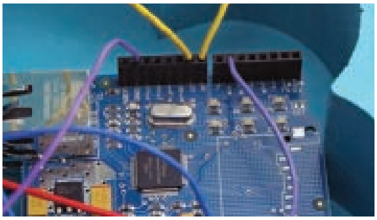


3f. Insulate all connections with heat-shrink tubing (I used clear heat-shrink here) or electrical tape.

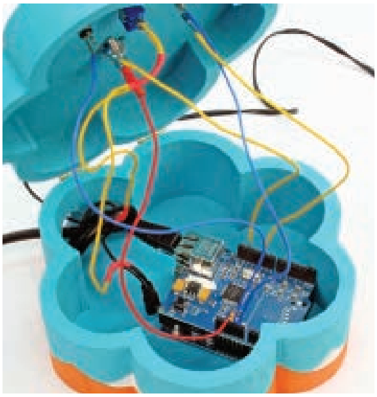


4. CONNECT EVERYTHING

4a. Fit the LEDs into their holders. Plug their negative leads into 2 ground (GND) header pins on the Arduino. Plug the positive lead of the blue LED into digital pin 8 of the Arduino and the positive lead of the green LED into pin 9.



4b. To wire the split lead from the wall anchor, plug the lead without the resistor into Arduino digital pin 6, and the resistor lead into ground. All done!

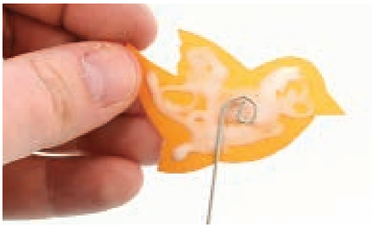


5. MAKE THE PAPER TOY

Kitty-wise, the most important part of this build is the actual toy that the cat plays with. You can use almost anything, from a feather or piece of cardboard to a lightweight manufactured toy. Just make sure the materials are 100% kitty friendly. And you can enhance your kitty's fun by adding some catnip!

5a. Draw a bird, or whatever you think might interest your kitty, onto a piece of paper. Once you have your final design, tape 2 pieces of paper together and cut the design out of both, to make 2 mirror images. I decided to add a few white paper highlights, and you could easily add additional detail with nontoxic markers.

5b. Add plenty of nontoxic glue to one side of a paper bird. Center the guitar wire loop in the middle, and then add the other bird cutout to the opposite side to create a paper-wire-paper birdie sandwich.



5c. Press the birdie between books or in binder clips while the glue dries. I decided to clip it and let it sit overnight. The end result was a durable and appealing birdie for my cat to attack!

NOTE: Go to makezine.com/22/kittytwitty to download papercraft bird costumes for your Kitty Twitty.

6. SET UP THE SOFTWARE

6a. Sign up for a new Twitter account (twitter.com), following the instructions to create a username and password. It's simple and free!

6b. Download and install the Arduino software (arduino.cc/en/Main/Software).

6c. Download and install NeoCat's Twitter Library for Arduino (arduino.cc/playground/Code/TwitterLibrary), which makes it easy for the code to connect to Twitter.

6d. Download and install Tom Igoe's String library (formerly TextString; arduino.cc/en/Tutorial/TextString), which simplifies the code to assemble random sentences.

6e. Download the Kitty Twitty source code, *KittyTwittyV8_user_removed*, from makezine.com/22/kittytwitty. Open the file in the Arduino application and find the line of code near the top of the program that looks like this:

```
Twitter twitter("user:password"); // replace the "user:password" with yours
```

As the comment directs, replace "`user:password`" with the username and password you created with your new Twitter account in Step 6a. Keep the quotation marks, and don't forget the colon (`:`) in between!

6f. To configure the network information in the code, find this section of code and replace the `ip`, `gateway`, and `subnet` values with your own values.

```
byte ip[] = { 192, 168, 2, 7 };          // a free IP address on your network
byte gateway[] = { 192, 168, 2, 1 };     // the gateway address of your network
byte subnet[] = { 255, 255, 255, 0 };    // the subnet mask of your network
```

To get these settings, start by looking at your computer's network settings. On a Mac, go to System Preferences/Network, then click the Advanced button and select the TCP/IP tab. On a PC, go to Start/Control Panel/Network and Sharing Center, then click View Status and Details.

For the code's free IP address, you can usually just take your network setting and increase the last number a little bit. In my case, my computer's address is `192.168.2.6`, so I tried `192.168.2.12` and it worked fine.

Next is the gateway address. On a Mac, this is listed as Router and on a PC, it's listed as Default Gateway. Mine is `192.168.2.1`. The subnet mask is generally `255.255.255.0`, but yours may be different, and it will also be listed in with your computer's network config information.

6g. Save the revised code, then upload it to your Arduino. With the Arduino environment already configured to recognize your port and board, this usually means just plugging it into your computer and clicking the Upload button. But if you're not sure how to do this, the Arduino website (arduino.cc/en/Guide/HomePage) has great tutorials, and the Resources section on the next page lists other ways to get started.

TIP: If you have trouble with any of the software setup, try posting in the MAKE forums (forums.makezine.com). They're filled with friendly and helpful people.

FINISH X

NOW GO USE IT »

USE IT.

START SPREADING THE MEWS

OPERATION

This is really easy. Simply plug in the power supply and Ethernet cable, and flip the switch. The green power LED should come on, and in a few seconds, the blue network status LED, too. The code tweets an "Up and Running" message to let you know everything is OK. You can plug a USB cable into the Arduino and listen in on the serial port for some debugging.

Every time the wire makes a connection, you'll see a new tweet! That's it!

VARIATIONS

You can modify this project to make almost anything send a tweet. It's a cat toy, but there's no reason it can't be converted into a Twittering dog toy, or even a Twittering bird perch. Just substitute a different kind of switch sensor for the bird-on-a-wire. Make a Twittering burglar alarm? Easy! Doggie door? Sure! Twittering fish? Now that's a challenge!

Also, you can add additional switches or sensors, connect them to as-yet-unused pins on the Arduino, and write some code to handle them. Think about adding a servo to make some random rumbles, or a speaker to simulate a bird. That should keep your cat's interest!

This project is still evolving, and I need to add more parts and experiment with them before I settle on the final Twittering toy. By the time you read this, I hope to have modifications that check whether your cat is sleeping or needs food, via pressure-sensitive piezos under its bed and food bowl. I also plan to add a speaker or small motor to get the cat's attention. See makezine.com/22/kittytwitty to learn more about these modifications.

RESOURCES

KittyTwitty project code, links, and other resources: makezine.com/22/kittytwitty

Arduino tutorials: arduino.cc/en/Guide/HomePage

Getting Started with Arduino by Massimo Banzi: Maker Shed item #9780596155513, makershed.com

Making Things Talk by Tom Igoe: Maker Shed item #0596510519

DOUBLE PENDULUM

By William Gurstelle

CHAOS ON A STICK

Devices that demonstrate true chaotic behavior (in a strict mathematical sense) are rare. Even rarer are chaotic devices that are easy enough for the typical maker to build at home and are interesting and beautiful. But one device nicely fits the bill: the double pendulum.

A double pendulum consists of a bar swinging from a pivot, with a second pendulum attached to the first bar's end. While the double pendulum is a simple physical system, you'd be hard pressed to find another device this simple that exhibits so wide a range of behavior. Give it a little push and the motion is fairly predictable. But give it a bigger push — bingo, welcome to chaos!

The double pendulum described here was designed with several options for demonstrating a variety of chaotic motions. With the right mounting, it's an interesting if not downright charming display that fits well into a number of settings, including classrooms, laboratories, and homes.

Photograph by Sam Murphy

Set up: p.95 **Make it: p.96** **Use it: p.99**

William Gurstelle (bill@makezine.com) is a MAKE contributing editor and the author of the book *Absinthe and Flamethrowers: Projects and Ruminations on the Art of Living Dangerously*.

Swing Thing

The Simple, Made Complex

What exactly is chaos? It means different things in different contexts. In common discourse, it means a confused, disordered state of affairs.

To the mathematician or physicist, chaos does not mean arbitrary or random motions and systems, nor does it mean that the outputs of a system are unrelated to its inputs. It does mean that the behavior of a system is, in a practical sense, unpredictable because small differences in initial conditions result in huge differences in subsequent actions. In a chaotic system — like the proverbial Amazon butterfly whose wing-fluttering can affect the weather in Europe — cause and effect are related but the complexity of the system makes accurate predictions impossible.

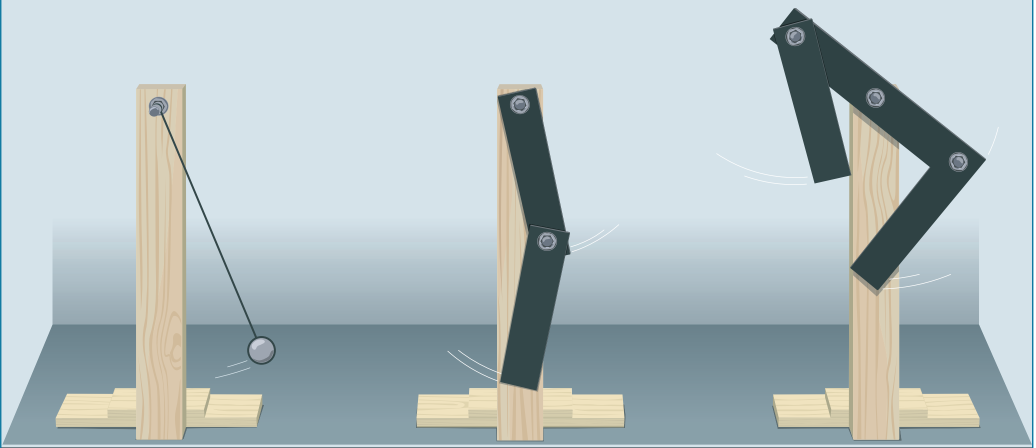
James Yorke of the University of Maryland is the mathematician who first introduced the term *chaos theory*. "The motion of a double pendulum," he says, "gets pretty complicated. But that's what chaos is."

"[The pendulum is] predictable in the short run but not in the long run," said Yorke in a recent *Washington Post* interview. "Chaos is about lack of predictability. Obviously, the spin of the pendulum is determined by physical laws, but it's very hard to predict because very small changes in the spin cause very big changes in the output."

Simple: Single Pendulum

Chaotic: Double Pendulum

Simple or Chaotic: Rott's Pendulum



Galileo Galilei became interested in pendulums as a university student in Pisa in the 1580s, when he observed a lamp swinging to and fro in a cathedral. His experiments led to his discovery in 1602 that the amount of time it takes for a simple pendulum to swing back and forth is dependent on the length of the pendulum, and not dependent on the weight of the bob or the size of the swing. A half-century later the scientist Christiaan Huygens made use of this feature, known as *isochronism*, by inventing the pendulum clock, which is still in use today.

The double pendulum doesn't exhibit isochronism. Though its construction is very simple, its motion is chaotic and impossible to predict, because very small changes in friction, initial drop height, temperature, and other variables have a large effect on its behavior over time. This sensitivity to initial conditions makes the double pendulum interesting to watch, as its pattern of movement is always changing.

In this configuration, first analyzed in 1970 by Swiss physicist Nikolaus Rott, a right-angled main pendulum joins a smaller side pendulum, and their 2 pivots are aligned horizontally at rest. When given a gentle push, the 2 arms will move in resonance with one another — but only if the ratio between their fundamental frequencies is 1:2.

Standard Rott Pendulum

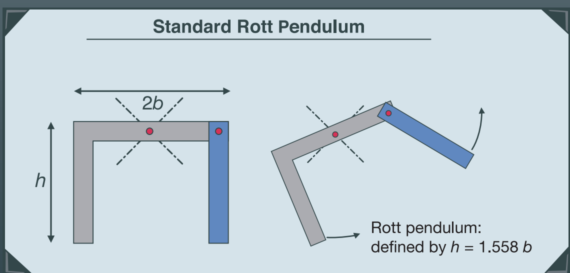
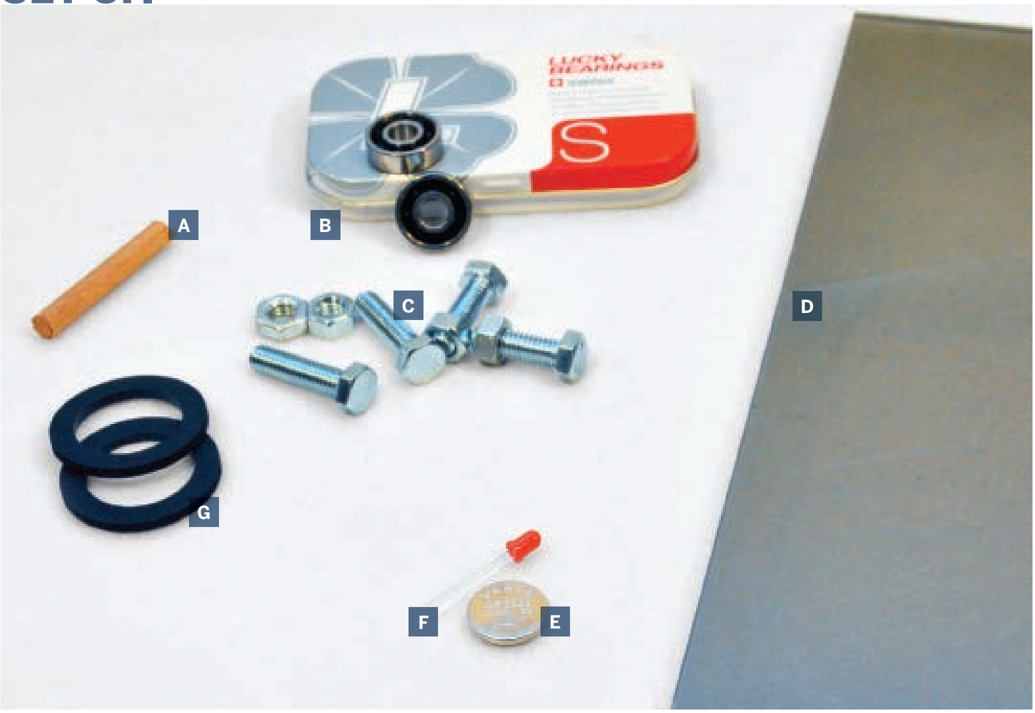


Illustration by Tim Lillis

SET UP.



Photography by Ed Troxell

MATERIALS

The pendulum itself may be fabricated from any number of common materials including plastic, aluminum, and wood; I used polycarbonate plastic.

The exact size of the pendulum may vary according to the wishes of the maker. I ordered my materials from McMaster-Carr (mcmaster.com) because they were easily available and not too expensive; you can also get parts from a local supplier, a surplus dealer, or another mail order supply firm.

[A] 8mm steel rod, 3" length for the main pivot on which the pendulums rotate. 5/16" wood dowel is an acceptable substitute, although you'll need to slightly build it out with tape or foil so it fits the bearing snugly.

[B] Skateboard bearings (7) High-quality bearings that reduce friction to an absolute minimum are the key to getting the best performance from your pendulum.

Skateboard bearings are relatively inexpensive high-performance bearings, sold in skateboard stores in quantities of 8, generally packaged in small metal cans resembling mint tins.

The quality of the bearing is determined by its ABEC designation: ABEC-3 bearings are good, ABEC-5 are better, and ABEC-7 or "Swiss" bearings are great. Buy the best you can afford.

[C] 5/16" bolts, 1" long, with nuts (2) for attaching pendulum bearings

[D] Sheet of polycarbonate plastic 12"×12"×¼" thick

[E] 3V coin cell battery (optional) to power the LED

[F] LED (optional) for time-lapse photography of pendulum in action

[G] Rubber washers, 1" ID (2)

[NOT SHOWN]

Nylon washers or plastic spacers

8mm shaft collar (optional)

TOOLS

Jigsaw, band saw, or table saw

Rotary tool or file

Rubber mallet

Epoxy glue

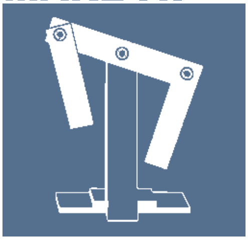
Sandpaper

Measuring tape

Electric drill with 22mm or 13/16" spade drill bits

Hacksaw if you're using steel rod

MAKE IT.



BUILD YOUR DOUBLE PENDULUM

START **Time: 1 Day Complexity: Easy**

1. CUT THE PENDULUM PARTS

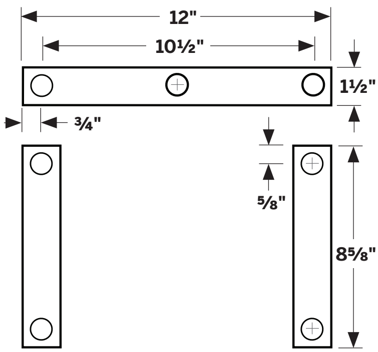
Cut the ¼" polycarbonate sheet into 3 pieces as shown in the Part Layout diagram (download at makezine.com/22/doublependulum): one long pendulum piece 2"×12" and 2 short pendulum pieces 2"×8⅝".

I cut these sizes so the pendulum can be used in a variety of configurations; you can use the long piece and one short piece to make a standard double pendulum, and add the second short piece to make a Rott's pendulum or a triple pendulum.

2. MEASURE AND DRILL BEARING HOLES

The high-performance skateboard bearings measure 22mm wide by 7mm deep, so you must drill a total of seven 22mm-diameter holes in the pendulum parts as shown on the Part Layout diagram, using a spade bit.

If you don't have metric drill bits, you can use a 13⁄16" spade bit and later enlarge the holes slightly with a file or rotary tool.



3. FIT THE BEARINGS IN THE HOLES

Use a rubber mallet to carefully tap the bearings into the holes so that the bearing face is perfectly parallel to the pendulum face. You may need to slightly enlarge the hole with a file or rotary tool. The bearing should fit snugly in the hole, but don't damage it by pressing too hard or whacking it too roughly with the mallet.

If the fit is too tight, slightly enlarge the hole. If you inadvertently oversize a hole and the fit is too loose, use fast-setting epoxy to secure the bearing in place.

4. MAKE THE PIVOT ROD

Cut a 3" length of 8mm steel rod (or 5⁄16" wooden dowel). This pivot rod will connect the pendulum to the support stand.

If you're using steel rod, I recommend that you slightly flatten the end of the rod nearest the pendulum, so the pendulum won't fall off when it's pushed forcefully. Grip the steel rod near the end in a vise, and hammer the end carefully to flare it just slightly.

5. BUILD A SUPPORT FOR THE PENDULUM

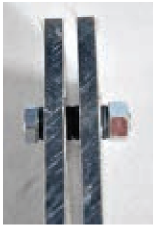
To support the pendulum, you can simply clamp a piece of wood to a vise on your workbench, or you can build a more elaborate stand from wood or metal. The only requirement is that the stand be solid and immovable when the pendulum is given a heavy push.

Attach the pendulum to the stand by drilling a 1½"-deep horizontal hole in the stand to accept the 3"-long pivot rod. To friction-fit the rod into the stand, this hole should be drilled with a 7mm or 5⁄16" bit. Also, the hole must be high enough so that no part of the pendulum touches the ground or benchtop when it swings. Insert the rod into the hole.

If you drilled entirely through the stand, I recommend putting an 8mm shaft collar on the opposite end of the shaft so it doesn't come out of the stand while spinning.

6. ASSEMBLE YOUR DOUBLE PENDULUM

To attach pendulum bearings to each other, use 5⁄16" bolts with nuts to make free pivots or fixed joints.

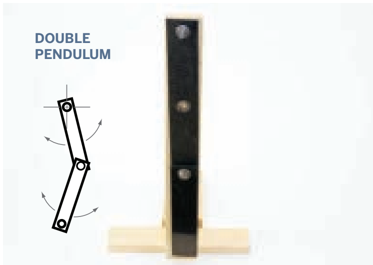


To adjust spacing between the pendulums, put nylon washers or other hard spacers on the bolt between the bearings to help space a pivoting joint. Place a flat rubber washer between the bearings to create a fixed, non-pivoting joint when the nut is tightened.

Build these 3 basic configurations following the diagrams:

Simple Double Pendulum

Mount one of the end bearings of the long pendulum onto the support rod or dowel attached to the stand. On the opposite end of the long pendulum, attach a short pendulum, using a pivoting joint.



Triple Pendulum

When all 3 pieces are allowed to swing from pivoting bearings, the system becomes a triple pendulum.

Don't push the bearing onto the pivot rod so far that the rod extends beyond the face of the bearing. If you do, it will interfere with the motion of the smaller pendulum.

You'll need to space the pendulums apart using plastic washers on the pivots so that they don't interfere with each other as they rotate.

Rott's Pendulum

Place the support pivot in the center bearing of the long pendulum. Then attach the 2 short pendulums to either end of the long one, fixing one of the joints at 90° and allowing the other joint to pivot freely. This creates a big L-shaped pendulum and a smaller side pendulum.

FINISH X

NOW GO USE IT »

USE IT.

PUSH IT REAL GOOD

EXPERIMENTS TO TRY

Set up your double pendulum and give it a little push. The motion is not particularly interesting. Then give it a forceful push. The chaotic motion of the pendulum becomes fascinating!

When you give the triple pendulum a strong push, it exhibits a similar chaotic motion. But as the system settles down, the 2 end pendulums start to swing back and forth in unison; that is, the second pendulum swings in resonance with the first.

Some more experiments to try:

» Note when the smaller pendulum changes direction and try to predict what initial conditions (e.g. position at time of push, force of push) result in similar direction changes.

» Rearrange the pendulums, bearing support, and bearing types to vary motions and behaviors.

» Affix a 3-volt battery to the bottom of the pivoting pendulum. Tape the longer lead of an LED to the positive side of the battery and the shorter lead to the negative side; the LED will light. Take a time-lapse photograph of the LED as it moves in chaotic fashion. Try different pushes.

VARIATIONS TO CONSIDER

Our pendulum has been designed so that it's simple to choose different pendulum lengths, support bearing locations, and joint types. With different pendulum geometries, a great variety of motions, from regular to chaotic, may be obtained. You can make new parts to experiment further.

Pendulum length: Parts may be cut to any size. The length affects the behavior of the system.

Support location: The placement of the support bearing controls the motion of the pendulum. Move it slightly or greatly off-center to see what happens.

Joint type: Experiment with pivoting joints and fixed joints at various angles to see how these affect motion.

Photograph by Sam Murphy

ROTT'S PENDULUM: HAVE IT BOTH WAYS

Involving a number of daunting differential equations, the mathematics that describe what's going on in a Rott's pendulum are extremely complex. But the upshot is that at small amplitudes (when given a gentle push) the 2 pendulums will remain in motion for a far longer time than either pendulum would move alone.

If you crunch through the math you'll find that when the ratio of the length of the cross-member of the L-shaped pendulum to the length of the other 2 legs is 1.283567 to 1, the resonant frequencies of the 2 pendulums are integer ratios of one another, and the 2 parts, although much different in shape, are resonantly coupled.

While it's difficult to make a Rott's pendulum precisely enough to exhibit perfect resonant coupling, with enough care, you can demonstrate the phenomenon. Give a well-made Rott's pendulum a small shove and it swings on and on and on; give it a big push and it will exhibit the wild, chaotic behavior characteristic of any well-made, low-friction double pendulum. It's the best of both worlds.

See Bill Gurstelle's video of building a double pendulum: makezine.com/go/doublependulum

SOLAR TRACKING PLATFORM

By Thomas R. Hughes

AUTOMATIC SUN-SEEKING FOR SOLAR GADGETS

This simple turntable platform uses a solar-powered motor and a strategically placed shade to automatically follow the sun, maximizing the potential of solar cookers, photovoltaic panels, or other devices.

I feel driven to use the sun however I can, and solar cooking is a great example. When the sun is shining out on my deck, I love being able to put some of those free joules into dinner rather than let them go to waste. And there's nothing more satisfying than capping off a sunny day by opening up and enjoying a pot of delicious, solar-cooked tandoori chicken.

There are some excellent solar cookers on the market, but most of them share one major drawback: failure to track the sun's east-to-west (azimuthal) motion. For these cookers to work their best, you need to reposition them every 20 minutes or so, which isn't always practical or convenient, to say the least.

Here's my solution: a simple wheeled platform that uses the sun's own energy to automatically follow its apparent motion. It's simpler and more versatile than other solar trackers I've seen, it stores easily, and the design can be made larger or smaller to match the size of your cooker.

Photograph courtesy of Thomas R. Hughes

Set up: p.103 Make it: p.104 Use it: p.111

Tom Hughes is a retired physics teacher who loves to make things and is a dedicated user of the sun. He has designed and built three solar cookers, patented a sidereal sundial, and has some other sundials in mind.

Seeking Sun / Seeking Shade

The solar tracking platform follows the sun thanks to a photovoltaic cell that keeps moving into the shade.

A The **sun** provides free energy as sunlight.

B A **solar cooker** turns sunlight into heat for cooking.

C The **turntable** supports the cooker.

D **Wheels** and a central **axle** let the turntable rotate, lazy-Susan style, atop the base.

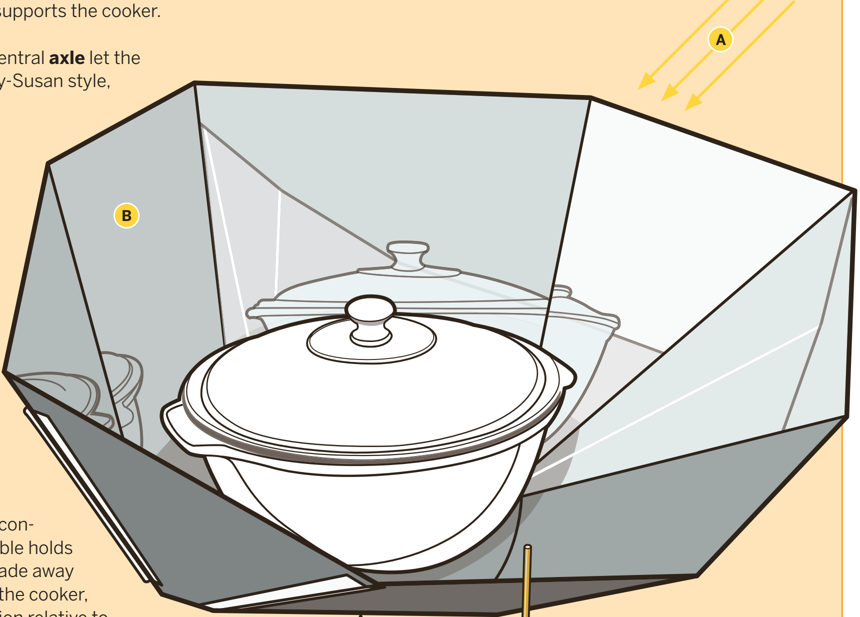
E A **photovoltaic (PV) cell**, aka solar cell, converts the sunlight that hits it into electricity to power the turntable's motor.

F A small **shade** keeps the PV cell out of direct sunlight for brief periods as the sun moves across the sky.

G A sliding **boom** connected to the turntable holds the solar cell and shade away from the shadow of the cooker, in a westward direction relative to the cooker.

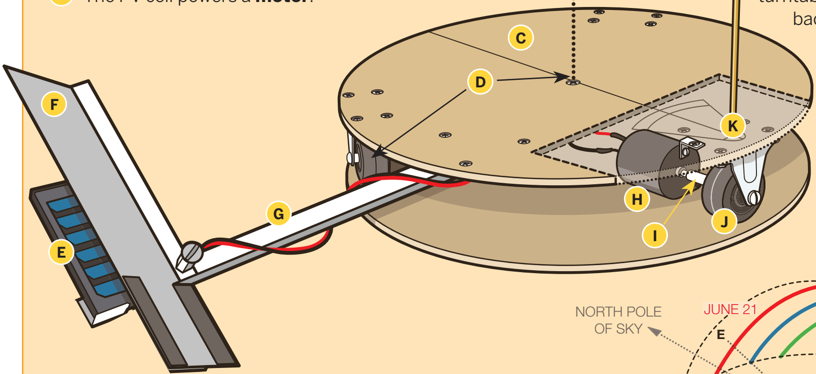
H The PV cell powers a **motor**.

I A **coupling** made from a bronze bearing with cylindrical shims and setscrews connects the motor's 0.159" axle to the drive wheel's ¼" axle.



J The **drive wheel** turns the turntable until the PV cell is back in the shade.

K A **brass tube** and **protractor image** act like a mini sundial for determining the optimal orientation for the cooker on the turntable.

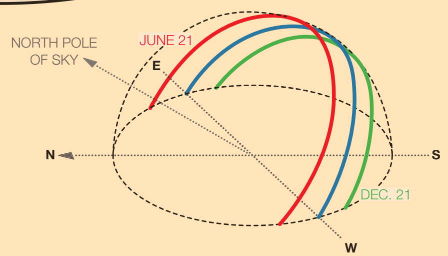


North Versus South

Northern Hemisphere: the cooker faces south and the platform turns clockwise, tracking the sun east to west.

Southern Hemisphere: the cooker faces north and the platform turns counterclockwise, also tracking east to west.

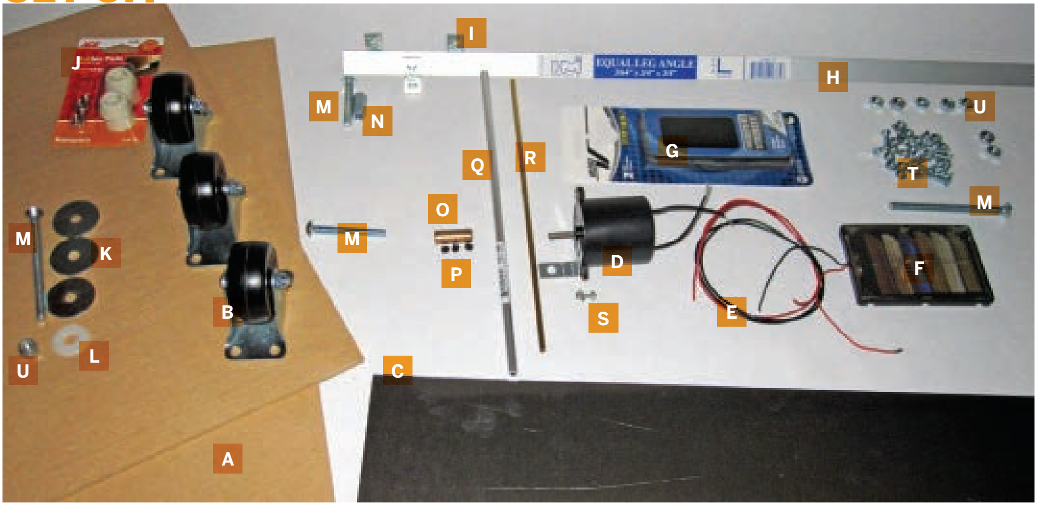
By sundown, you have a delicious slow-cooked meal!



AZIMUTHAL TRACKING Apparent east-to-west motion of the sun in the Northern Hemisphere, on solstices (red, green) and equinoxes (blue)

Illustration by Damien Scogin

SET UP.



MATERIALS

This project is sized for my HotPot Simple Solar Cooker, which has a footprint 11" square and a reflector array that fans out 31"×26" deep and 14" high. But you can modify the platform to fit other cookers, provided that the photocell, motor, and wheels will all work together.

[A] ¼" medium-density fiberboard (MDF) enough for two 16" square pieces

[B] Non-swivel wheel assemblies, 2⁷⁄₁₆" tall (3) One of them must have a removable axle. Check a local hardware store.

[C] 0.025" aluminum sheet, 6"×18"

[D] 3V, 1rpm motor with enough torque to rotate the turntable and a diameter smaller than the wheels, such as part #3041327 from Edmund Scientific (scientificsonline.com), $25; or #A3Z16-0010A from SDP/SI (sdp-si.com), $30

[E] 20-gauge stranded insulated wire, red and black, 20" each color

[F] 3V photovoltaic cell powerful enough to drive your motor, such as item #4-3.0-100 from Solar World (solarworld.com), $16; or #3037334 from Edmund Scientific, $20

[G] Velcro tape, 2"×4" strips, industrial strength, 1 package

[H] Aluminum angle, ¾"×¾"×³⁄₆₄" thick, 6' length or use ¼" thick

[I] Corner braces: ¾"×¾"×½" wide (3); 1"×1"×½" wide (1)

[J] Rubber feet, at least ⅜" tall, package of 4 with screws

[K] Fender washers, ¼" I.D., 1¼" O.D. (3)

[L] Nylon washer with I.D. at least ¼" and O.D. between ⅞" and 2"

[M] ¼-20 machine screws: round head, 1½" long (1); round head, 2" long (1); flathead, 3½" long (2)

[N] Coupling nut, ¼-20, ⅞" long

[O] Bronze bearing, ¼" I.D., ⅜" O.D., 1" long

[P] #10-32×³⁄₁₆" setscrews, (3)

[Q] Aluminum tube, ¼" O.D., 0.049" thick, at least ¾" long such as part #3061 from K&S Engineering (ksmetals.com)

[R] Brass tube, ⁵⁄₃₂" O.D., ⅛" I.D., at least 6" long K&S Engineering #128

[S] #4-40×½" machine screw, round head, with nut and washer, ½" long

[T] #8-32×½" machine screws, flathead, with nuts, (16)

[U] ¼-20 nuts:
- **⅛" thick (2)**
- **⁷⁄₃₂" thick (5)**
- **stop nut (1)**
- **⅛" thick jam nuts (2)**

[NOT SHOWN]

Solar cooker Visit makezine.com/22/solartracker for sources

Electrical tape or liquid electrical tape

Epoxy for metals

Polyurethane sealer

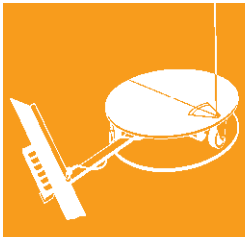
Silicone caulk

TOOLS

- **Drawing compass** with at least a 7½" radius
- **Protractor**
- **Electric drill or drill press with a countersink and assorted bits: ¼", ¹⁷⁄₆₄", #21 (0.159"), ⁵⁄₃₂"**
- **Dremel with a grinding tip**
- **#10-32 thread tap and handle**
- **Hex key** for setscrews
- **Vise**
- **Clamps (2)**
- **Hammer**
- **Center punch**
- **Reciprocating saw (aka sabre saw) or band saw**
- **Hacksaw**
- **Sanding block and sandpaper**
- **Pliers**
- **Sheet metal bending pliers**
- **Screwdrivers**
- **Crescent wrenches**
- **Soldering iron and solder**
- **Metal file**
- **Sharpie with ultra-fine point**
- **Disposable brushes**
- **Access to a copying machine**

Photography by Thomas R. Hughes

MAKE IT.



BUILD YOUR SOLAR TRACKING PLATFORM

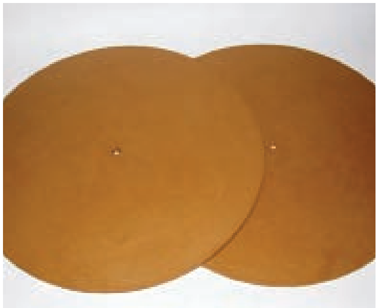
START **Time:** 7 Hours **Complexity:** Moderate

1. MAKE THE TURNTABLE AND BASE

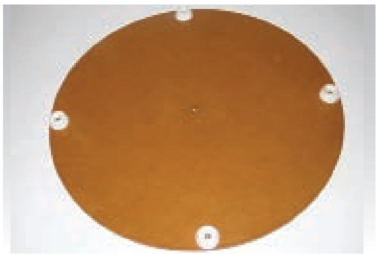
1a. Cut the fiberboard into two 16" squares, mark their centers, and then scribe a circle with a 7½" radius on each. Use a band saw or saber saw to cut just outside the circles, and sand them down to smooth 15" circles.

1b. Drill and countersink a ¼" hole in the center of one disk; this disk will be the turntable. Drill a 17/64" hole centered in the other disk, the base.

1c. Brush a polyurethane sealer over each disk, let dry, and add a second coat. Repeat on the other sides and around the edges.



1d. Mark 4 quadrants on the base disk, drill pilot holes for the screws used to mount the feet, and install the feet. File down the tips of any screws that pierce the top surface of the base disk.

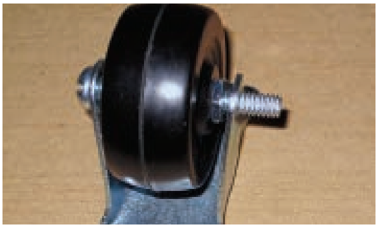


1e. Gently sand the top surface of the base disk and apply a third coat of polyurethane.

1f. Remove the axle from one of the wheels and bend both of its mounting flanges outward so that their tips are 1 13/32" apart. This will be the drive wheel.

1g. Clamp the 2" round head screw in a vise, and file ⅜"-long flats on opposite sides of its tip.

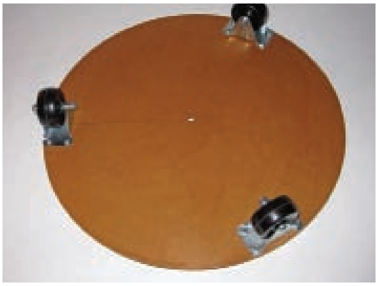
1h. Reassemble the drive wheel with the filed screw as its new axle and with the 2 jam nuts locking the wheel to the screw. Check that the wheel and axle turn freely.



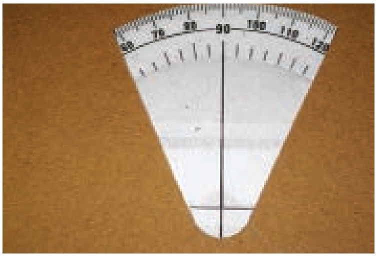
1i. Draw three 120° sectors on the underside of the turntable disk and use a wheel assembly to mark mounting holes for each wheel, spacing them equidistant around the perimeter. Center-punch and drill holes for the 12 mounting screws using a #21 bit.

1j. At the drive wheel's location, drill a fifth, 5⁄32" hole centered between the 4 mounting holes. On the top of the turntable, draw a diameter line that passes through this 5⁄32" hole (as seen in the photo in Step 1n, following page). Countersink the 12 mounting holes, but not the 5⁄32" hole.

1k. Install the 3 wheels on the underside of the turntable, locating the modified drive wheel over the 5⁄32" hole.

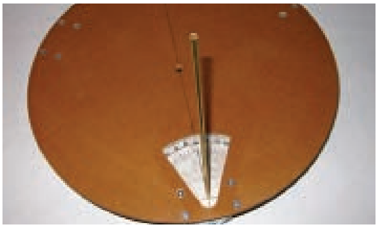


1l. Make a photocopy of your protractor. Draw a line on the copy from the 90° mark down through the origin. If it has an inner set of numbers, white them out with correction fluid. Make a copy of the modified copy, and cut it into a neat wedge that includes the origin and the range of degrees from 60 to 120.



1m. Paint the back of the protractor cut-out with polyurethane, then stick it to the topside of the turntable, with the origin centered over the 5⁄32" hole and the 90° mark lined up with the diameter line from Step 1j. Apply more polyurethane over the paper as a sealer.

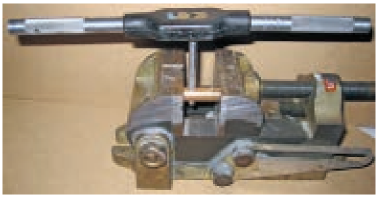
1n. When the polyurethane is dry, run the 5⁄32" drill bit through the protractor image's origin point, so the 5⁄32" brass tube can be mounted in this hole when needed.



2. INSTALL THE MOTOR

2a. Cut ¾" lengths of both the ¼" aluminum and the 5⁄32" brass tubing, to make 2 cylindrical shims. Clamp the aluminum shim in a vise and enlarge its inner diameter by drilling with a #21 bit. Check that the 2 shims nest together and will slip over the motor shaft and fit into the bronze bearing.

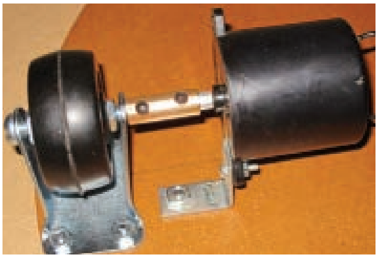
2b. File a ⅛"-wide flat on one side of the bronze bearing, then center-punch marks on that flat, ¼" in from each end. Use a #21 bit to drill through the bearing at each mark, then use a #10-32 tap and handle to thread each hole for the setscrews.



2c. Slip the bearing over the drive wheel's axle, install 2 of the setscrews at the wheel end of the bearing, and make sure the wheel turns freely. Slip the nested shims over the motor's drive shaft, then slip the shims and drive shaft into the other end of the bearing. Make a mark through one of the remaining setscrew holes with a fine-tipped marker, then use the narrow edge of a file to file slots through the shims that will permit the third setscrew to reach the flat on the motor's drive shaft.

WARNING: Never apply torque to the motor's shaft; you may strip its gears!

2d. Use the #4-40 screw, nut, and washer to attach one mounting flange of the motor to the 1"×1"×½" corner brace. Fit together the drive wheel, coupling, and motor shaft, keeping the motor's flanges as horizontal as possible and the corner brace flush against the underside of the turntable. Mark and drill a #21 hole for the screw to anchor the corner brace; it will be off to one side from the drive coupling. Countersink the hole on the topside of the turntable and install a ½" flathead screw with a nut underneath to anchor the motor. Install the third setscrew to fix the bearing to the drive shaft.



2e. With the turntable still inverted, lay the base disk on the wheels and check whether the motor's unused mounting flange sticks up to touch the base disk. If so, file it down to open up some clearance.

3. MAKE THE BOOM

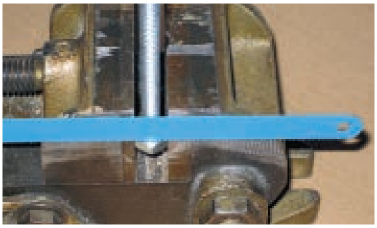
3a. Cut a 14½" length of the aluminum angle and drill a ¼" hole 2¾" in from the right end, centered in the bottom leg of the "L."

NOTE: These instructions are written for use in the Northern Hemisphere. If you'll use your solar tracker in the Southern Hemisphere, you'll need to translate the holes and cuts in this step to the opposite sides of the boom, so that the boom will extend from the left side of the turntable instead of the right. In either hemisphere, the boom extends to the west.

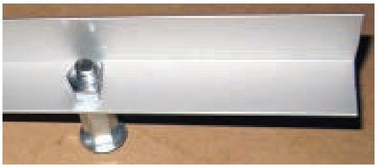
You'll also need to orient the PV cell so that it faces north instead of south, and reverse the motor wiring so that the turntable rotates counterclockwise.

3b. Cut the 1½"-long ¼-20 round head screw down to 1⁵⁄₁₆" and mount it tightly in the coupling nut.

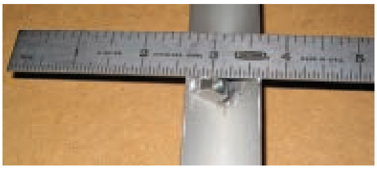
3c. Select one of the 3½" screws as a "sacrificial" screw. Mount a ⁷⁄₃₂"-thick ¼-20 nut near its end, clamp the nut in a vise, and cut off one face of the nut right up to the threads on the screw.



3d. Thread the coupling nut and screw through the back of the hole in the aluminum angle and screw your modified nut down onto the inside face, making sure this nut's cut-off side is facing the right end of the boom.

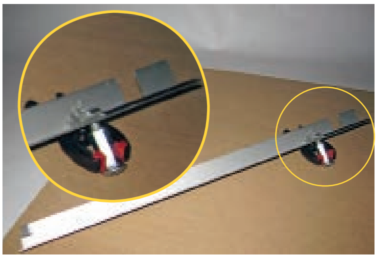


3e. Mix some metal epoxy and apply it generously between the nut and the inside of the boom, gluing the nut down so that its cut side faces the right end of the boom. After the epoxy cures, use a Dremel tool to grind the nut down flush with the edges of the angle, so the boom can be stored flat against the turntable.



3f. Again at the right end of the aluminum angle, cut out a ⅜"-wide notch, 1⅛" to 1½" in from the end and on the opposite leg of the angle from the epoxied nut. On the left end of the notched leg, make a ⅜"-deep cut and bend the resulting tab outward.

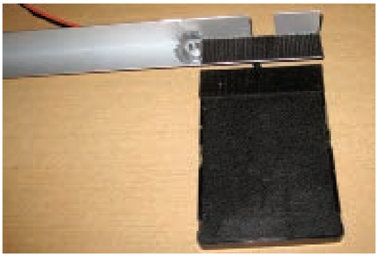
The wide notch will accommodate the PV cell's wires, and the tab will prevent the boom from being pulled out too far.



4. ADD THE PV CELL AND SHADE

4a. Apply a dab of silicone caulking where the wires exit the photovoltaic cell, for strain relief.

4b. On the boom, install velcro tape from the epoxied nut to the closest end. Stick a mating piece of velcro to the back of the PV cell, at the end with the wires.

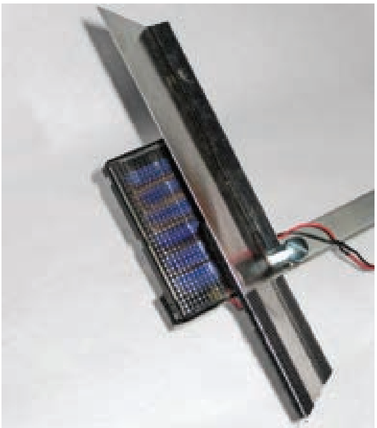


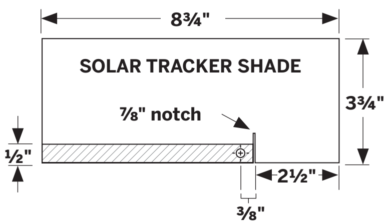
4c. Solder a 20" length of red wire between the PV cell's red lead and the motor's negative terminal lead. Solder a 20" length of black wire from the cell's black lead to the motor's positive lead (which is also black). Twist the stripped wire ends together without soldering them, and wrap the connections with electrical tape, but don't consider them final; you may have to swap the motor connections later.

4d. For the shade, cut a 3¾"×8¾" rectangle from the aluminum sheet and file the edges smooth.

4e. Cut and drill the shade following the diagram shown below. (Download the template at makezine.com/22/solartracker.) Drill the ¼" hole and cut a saw-blade's-width notch as shown, then bend the crosshatched portion back 45° (bend it the opposite direction for Southern Hemisphere use). This notch should fit over one edge of the boom to help anchor the shade.

4f. Test-assemble the boom, cell, and shade. Velcro the PV cell to the end of the boom, then fasten the coupling screw and nut to the boom through the mounting hole in the shade. The shade should sit tilted over the PV cell, and the cell's wires should thread through the slot in the boom.





5. ASSEMBLE THE PLATFORM

5a. Poke the non-sacrificial 3½" flathead screw through the hole in the topside of the turntable disk, invert the disk, and then tighten down a fender washer and two ¼" nuts against the underside. This will be the turntable's central axle.

5b. Thread on 2 more nuts, another fender washer, the nylon washer, and the last fender washer. Slip the base disk over the axle with its feet facing up. Adjust and lock together the two ¼" nuts so that, in this inverted configuration, the base disk sits just above the upper washer.

5c. With the turntable still inverted, install the ¼-20 stop nut, and make sure the disks can rotate freely. Measure how much of the 3½" axle protrudes above the stop nut. Disassemble the turntable, cut off this protrusion, and file the end smooth.

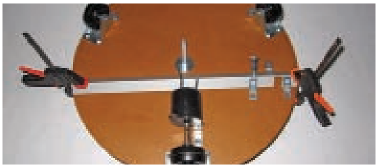
5d. Bend the three ¾"×¾"×½" corner braces open to an angle of 135°.

5e. Reinstall the central axle, the first washer, and two ¼" nuts on the turntable disk.

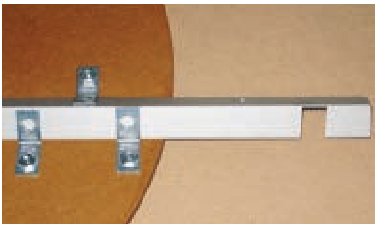
5f. Partially screw the coupling nut and screw back into the underside of the epoxied nut. (This is its storage location.)

5g. Draw a line across the disk between the motor and the fender washer, about ¼" from the washer and parallel to the 2 free-turning wheels.

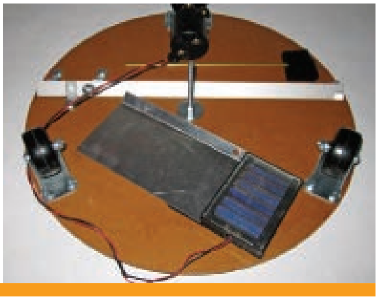
5h. Clamp the boom along this line with the corner edge up and the notch facing the drive side. Space the 135° corner braces around the notch, positioned to hold the boom in place from both sides.



5i. Mark and drill #21 mounting holes for the 3 braces, countersink them on the top, and secure them with ½" flathead screws and nuts. Remove the screw with the coupling nut and adjust the braces so that the boom slides in and out easily but not freely.



5j. All the pieces are built; the last step is to add more velcro so they store together easily. Arrange the PV cell, shade, and brass tube on the underside of the turntable disk near the edges, and velcro-tape them in place. Go for convenience; you shouldn't have to disassemble the base to reach these parts. I store the PV cell velcroed to the shade between the free wheels, and use 3 tabs of velcro to hold the brass rod. The coupling nut and screw stow screwed into the retracted boom.



6. TEST AND ADJUST

6a. On a sunny day, secure the base onto the central axle with the nuts, washers, and stop nut, and then turn the platform right side up. Extend the boom, wrap 2 or 3 turns of the red and black wires around it, and mount the PV cell and shade as in Step 4f.

6b. Place the platform on a flat surface in the sun and orient it so that the entire PV cell is illuminated. If the wiring is correct, the turntable should rotate clockwise until the surface of the PV cell is only partially illuminated. Tracking has begun! But if the turntable rotates counterclockwise (and you're in the Northern Hemisphere), you need to swap the motor connections. Solder them when they're correct, and cover them with electrical tape.

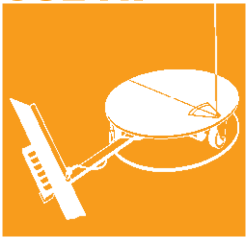
6c. To determine the platform's central tracking angle — its optimum orientation — install the brass tube (the gnomon) in its hole and position the tracker so that its PV cell is fully lit by the sun. Watch it for several cycles, noting the shadow's positions on the protractor when the motor starts and stops. The average between these 2 readings is the central tracking angle.

This number varies depending on the time of year, so it's a good idea to recalibrate if you haven't used the cooker in a while.

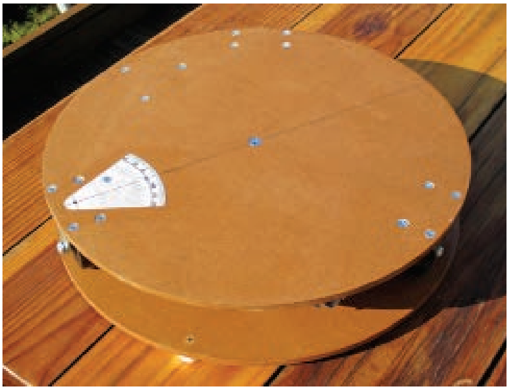
You're done, and ready to maximize some solar energy!

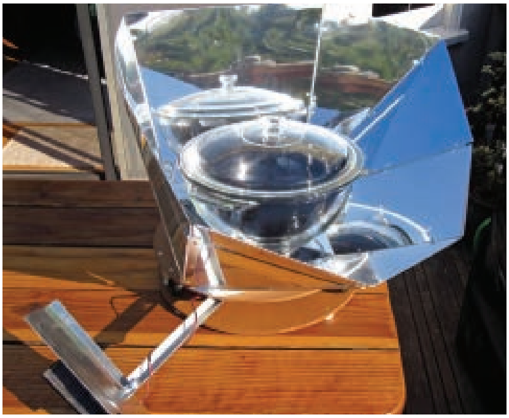
FINISH X **NOW GO USE IT »**

USE IT.



COOK UP SOME SOL FOOD





SEASONAL CUISINE

To use the tracker, bring it out into the sun, give it a few minutes to start tracking, and position your ingredient-filled cooker and reflector on top, aligning it to face along the central tracking angle (determined in Step 6c). Then, just let the sun do the rest.

With my solar tracker, the motor kicks in when about ½" of the PV cell comes into direct sun, which means about 75% of the cell stays in the shade. The platform rotates about 4° for each correction, so it tracks the sun's motion with an error of ± 2°.

In the San Francisco Bay Area from about March to November, I have had particularly good results cooking Cornish game hens with vegetables, tandoori-style chicken, burgundy beef stew, salmon loaf, lentils, beets, and potatoes.

Most one-pot slow-cooker recipes will work well, and I look forward to expanding my repertoire. Crock-pot or slow-cooker cookbooks will yield a wealth of ideas, and some of my favorite recipe sources are listed at makezine.com/22/solartracker.

I tested my HotPot solar cooker on a clear day last May, putting 750ml of canola oil in the pot at 10:10 a.m. It took about 45 minutes for the oil to reach 212°F. The pot stayed above 212° for 6½ hours and maxed out at 315°.

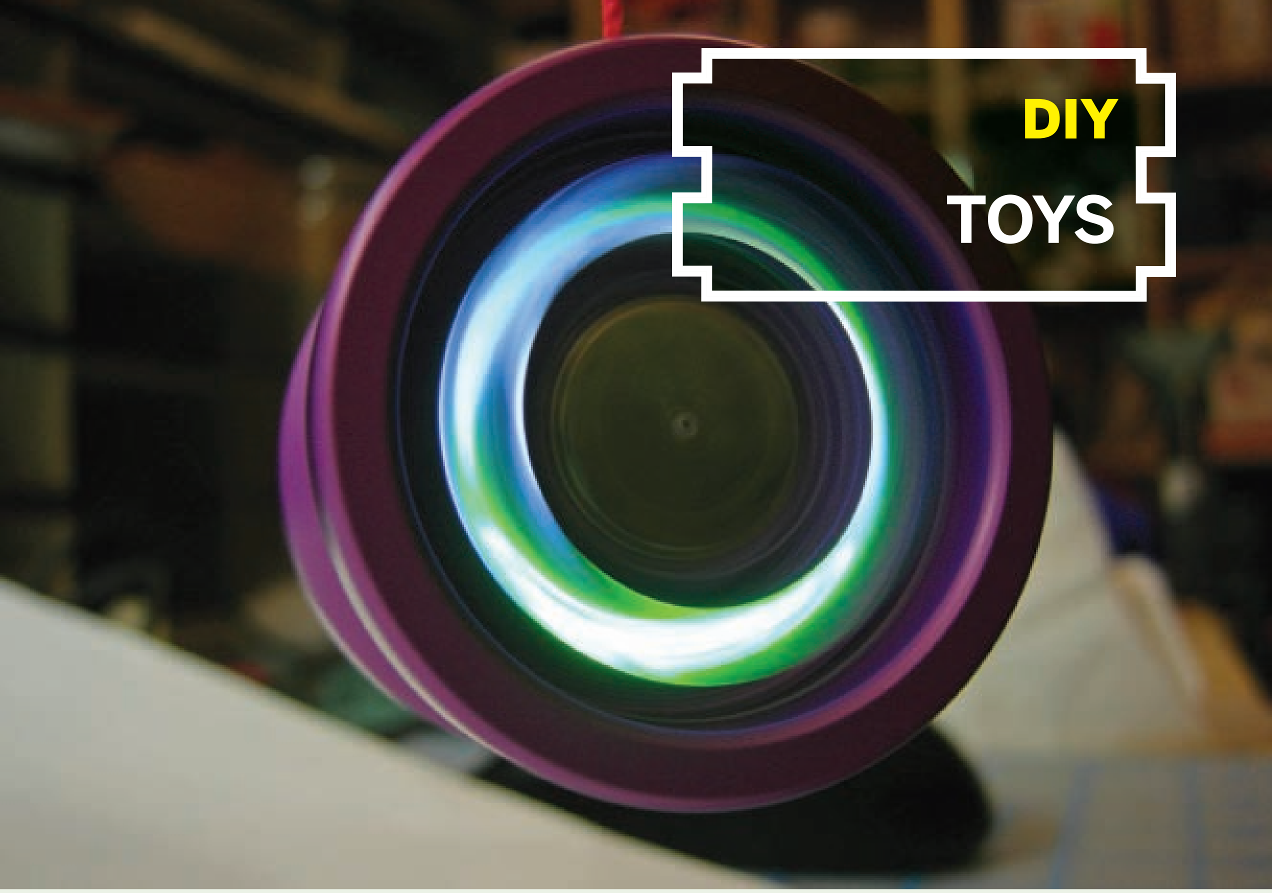
If your cooker gets too hot, rotate it (*not* the platform!) counterclockwise so that it will track some number of degrees behind the sun. But don't apply torque to the drive wheel in the process!

Depending on your space limitations and the season, you may choose to leave the platform with its boom extended and solar cell attached for months at a time, but don't leave it outside when you aren't using it.

OTHER APPLICATIONS

Beyond cooking applications, you can also use the platform to speed up photovoltaic battery chargers. And someday, someone who is experimentally inclined might conceive of a neat way of adapting this device to also track the sun's altitude, or to orient a solar-powered food dehydrator, or to distill seawater. The possibilities are fun to contemplate.

+ Visit makezine.com/22/solartracker for solar cooker information and recipe sources.



LED YO-YO SIDE CAPS

Spin-activated lights for your butterfly.

By Eric Chu

There aren't many low-budget ways to customize one's yo-yo. The most common ones are painting or dyeing; both look great, but they're limited: paint chips off, and dyeing is only for plastic yo-yos.

Being a yo-yo fanatic, I regularly visit the blog yoyoskills.com for yo-yo news. There I recently read about spin-activated LED side caps that fit into the side of yo-yos. These are low-cost ($6) and look very cool; unfortunately, they come in only one size, thus fitting only a few yo-yos.

I thought it'd be a fun project to make my own set (and it was!). Here's my guide to making your own. I used a modern One Drop Project butterfly yo-yo, but you can choose any yo-yo that's got concave sides.

How It Works

Using the centrifugal force generated by the spinning yo-yo, the spring, acting as the switch, is pulled

MATERIALS

- **Yo-yo with concave sides. For more space and greater stability, pick one with a flat hub and inner rim.**
- **Thin plastic sheet**
- **5mm LED (2 per cap)**
- **Lithium coin cell battery**
- **Hot glue**
- **Magnet wire**
- **Double-sided tape**
- **Aluminum insulation tape**

TOOLS

- **Drill and #9 drill bit**
- **Needlenose pliers**
- **X-Acto compass cutter**
- **Caliper**
- **Straightedge**
- **Pen**
- **Sandpaper**

Photography by Eric Chu

Fig. A: Calipers give an accurate inner diameter of your yo-yo. Fig. B: Set the compass cutter to match the inner radius. Fig. C: Cut the side cap out of sheet plastic. Fig. D: Measure your coin cell battery, then lightly scribe a matching circle in the center of the cap. Fig. E: To mark the LED positions, scribe 2 opposite arcs in between the battery circle and the cap's edge. Then lay a straightedge across the center. Fig. F: The cap with LED holes drilled.

outward. It makes contact with the positive leads of the LEDs, thus completing the circuit and turning the LEDs on.

1. Cut, mark, and drill the side cap.

1a. Measure the inner diameter of your yo-yo with a pair of calipers as shown in Figure A, then divide by 2 to get the inner radius. Slide the caliper to this number and set the compass cutter to align with the tips of the caliper (Figure B). Tighten the knob on the cutter to lock it in place.

1b. Use the compass cutter to cut out a side cap from the plastic sheet (Figure C). Test-fit the cap to see if it fits into the yo-yo.

1c. Measure the diameter of your lithium battery, divide by 2 to get the radius, and set the position of the compass cutter to the radius (Figure D). Lightly mark the circumference of the battery onto the cap. Later, you'll use this to center the battery.

1d. Reset the compass cutter so that the blade is between the circumference of the cap and the battery mark. Lock it and lightly mark 2 arcs across from each other (Figure E), for positioning the LEDs.

1e. Use a pen to mark the 2 points for drilling the holes for the LEDs. To do this, place a straightedge across the 2 arcs you drew and center it on the center point of the cap.

1f. Drill out the #9 holes on your cap (Figure F). The #9 drill bit makes holes the right size for 5mm LEDs to be press-fitted.

2. Assemble the cap.

2a. Insert LEDs into the holes "bulb" first, with their leads aligned parallel to one another (Figure G). Make sure the longer (positive) leads are both facing the same direction and the shorter (negative) leads are as well.

2b. Bend the negative leads to meet each other, as shown in Figure H. Make sure they're in contact with each other. Notice that the leads are passing through the area where the battery will sit.

2c. Apply hot glue to the cap in 2 places as shown, and press the negative side of your battery onto the glue, making sure both negative leads touch the negative side of the battery (Figure I).

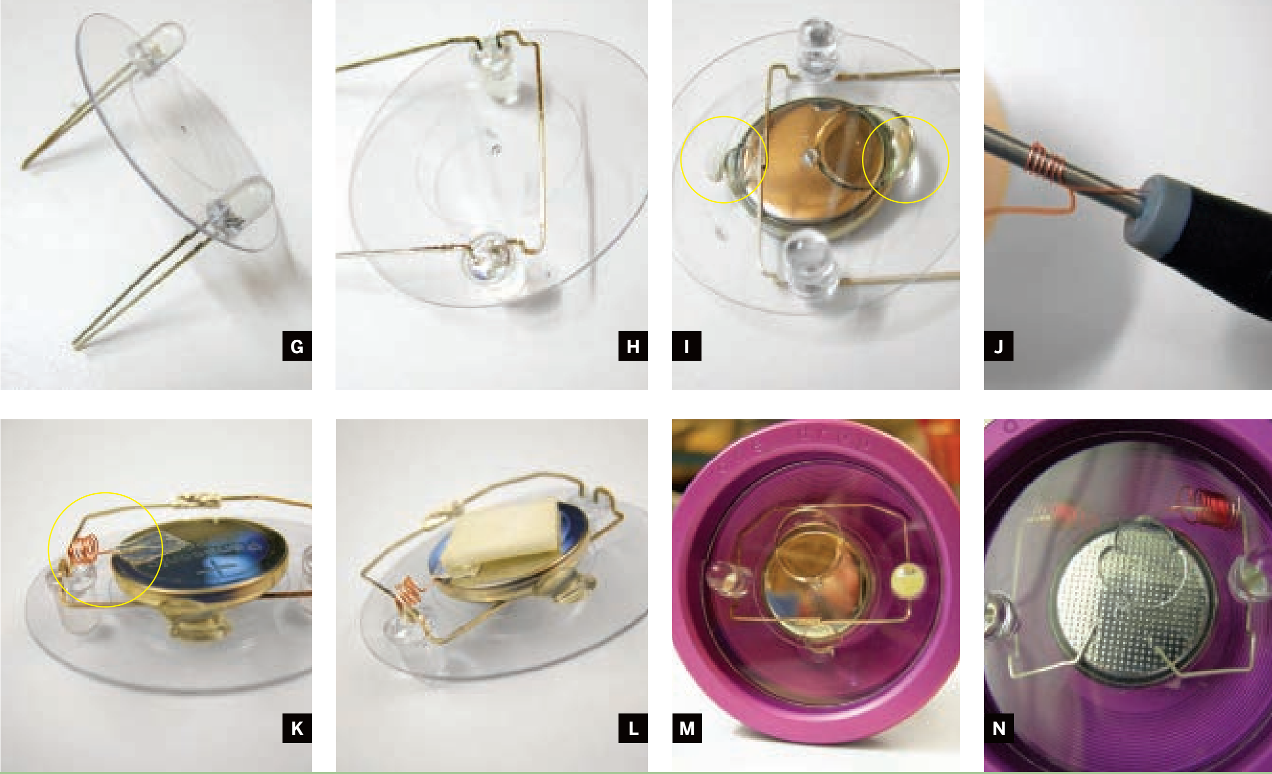


Fig. G: LEDs press-fit into holes. Fig. H: Bend the LEDs' negative leads to meet. Fig. I: Glue the battery's negative side to the cap so the negative leads are touching it. Fig. J: Coil wire around a small screwdriver to make a spring. Fig. K: With conductive tape, tape the positive leads to each other, and tape the spring to the battery. Fig. L: Double-stick tape on battery. Fig. M: Finished cap in place. Fig. N: Initial design: 2 springs, twice the trouble.

2d. Make your spring. First strip the enamel coating off your magnet wire by folding a piece of sandpaper in half and running about 3" of wire between the grit. Sand the wire until you see the bare copper, but don't over-sand or the wire might break.

Tightly wrap the wire around a small screwdriver or the ink cartridge of a ballpoint pen, leaving about ½" uncoiled at the end (Figure J). Coil the wire 5 times around, and cut off the spring.

2e. Bend the positive LED leads to meet each other, then tape them together by wrapping a piece of aluminum insulation tape around both leads. Tape your spring to the battery with aluminum tape (Figure K). Adjust the spring to sit as close as possible to the positive leads without touching them. Pliers come in handy.

2f. Stick a piece of double-sided foam tape onto the battery (Figure L), then stick it to your yo-yo (Figure M) and you're done!

Troubleshooting

Q: Why don't the LEDs light when I throw my yo-yo?
A: Move the spring closer to the positive leads. Check the polarity of the LEDs (+ to + and – to –).

Q: Why do the LEDs stay on after throwing?
A: Move the spring slightly farther back, away from the positive leads.

Improvements

This is my second prototype and I'm already thinking of newer designs. Using multicolor LEDs like the retail version would be a nice addition.

To keep the yo-yo spinning smoothly, make sure all the parts are centered to the rotational axis. Less mass on the caps will also lessen the wobble caused by any off-axis components.

In my first design (Figure N) the LEDs stayed lit after just one throw. Since copper wire isn't the springiest, and there was too much wire, it pulled itself toward the leads too much. Also, using 2 springs caused twice the problems!

DIY LED side caps video: makezine.com/go/yoyo

More on LED side caps: yoyoskills.com/?p=2608

MAKE engineering intern Eric Chu throws yo-yos and builds robots. He is the creator of Chu Pads, friction pads for bringing yo-yos back up, and is developing silicone response pads.

LET THEM EAT CHEESE

Fermenting your own cheese is easier than you think. By Wendy Tremayne

Libby Reinish and Tristan Chambers, urban homesteaders and defenders of culture (bacterial and social), know that ingenuity can stave off a mundane world of mass production in which machine-made standbys replace all that once contained the mark of creativity. They also love cheese.

Their courtship with cheese is nurtured in between school, work, gardening, beer brewing, and dumpster diving for DIY projects. They've made soft goat cheese, chevre, feta, ricotta, mozzarella, and a hard cheese similar to Parmesan.

Cheese making is an ancient love affair, a trilogy in which mammal, maker, and microorganism intermingle with delectable results. Reinish and Chambers say that cultural impressions appear in the relationship between people and the food they eat.

"Most [people] won't attempt the art of cheese making because of the modern preoccupation with bacterial contamination," they relayed. "We've really sanitized our relationship to fermented foods."

In contrast, the French palate recognizes cheese as a part of the living world. Advertising guru G. Clotaire Rapaille revealed, in an interview with Doug Rushkoff, that he advised the industry to package cheese in plastic zip-lock "body bags" made for refrigerators (which he likens to a morgue). In his view, this kind of packaging gives Americans what they expect: dead food.

But the cheese maker knows that flavor requires oxygen exchange and humidity; cheese breathes. While the cheese dome offers a decent storage solution, one might have to make a trip outside the supermarket to actually find a living cheese. Or do it oneself. Here's a recipe from Reinish and Chambers for an herbed goat cheese.

Photography by Daniel Long

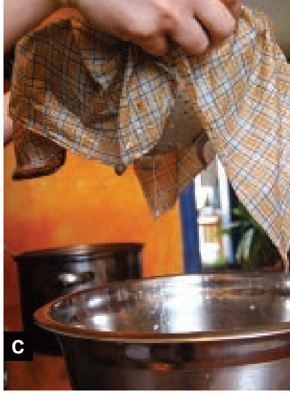


Fig. A: We used goat milk, organic buttermilk, and vegetarian rennet for our cheese. Fig. B: To separate the curds and whey, ladle the mixture into a sterilized handkerchief in a colander. Fig. C: Much of the whey will run out through the bottom of the colander. Fig. D: Gather the corners of the handkerchief with a rubber band. Fig. E: Suspending the handkerchief from your kitchen sink faucet is a good option. Fig. F: Add salt and herbs, and enjoy!

INGREDIENTS AND TOOLS

1gal goat milk
¼c buttermilk
Rennet traditional or vegetarian
1½tsp salt
Dried herbs
Clean handkerchief
Large stainless steel pot with lid
Colander, and thermometer

1. Warm the milks.

Sterilize a pot by boiling a ¼ cup of water for 5 minutes with the lid on, then discard the water. Combine the milk and buttermilk in the pot, and heat the milks to room temperature (65°F) over a low flame.

2. Add rennet and let sit.

Prepare the rennet, following the directions on the package (typically you add ¼ tablet of traditional or 20 drops of vegetarian), and then add it to the pot. Stir well to combine.

Let the mixture sit undisturbed at room temperature overnight. If you jiggle it, the milk won't form a curd. In about 12 hours the milk should have formed a curd (you should be able to slice it with a knife). If not, let it sit for up to 18 hours until the curd is well formed. If you rush this step, you'll have a hard time separating the curds and whey.

3. Separate the curds and whey.

Boil the handkerchief to sterilize it, and spread it out in a colander. Cut the curd into 1" cubes with a long knife. Ladle them into the handkerchief (Figure B).

Take the handkerchief by the corners, and gather the corners together with a rubber band (Figures C and D). Hang the curd-filled kerchief somewhere that it can drain overnight. Try in your fridge over a bowl, or suspended from your sink faucet (Figure E).

4. Add seasonings and enjoy.

When the cheese is done draining, it will be moist but hold its shape. Add salt and herbs of your choice (Figure F). We used garlic and dill for this cheese.

Resources

» **The Cheese Page:** makezine.com/go/fankhauser
» **Libby Reinish's site:** whittleddown.com

Wendy is an event producer, artist, and yoga teacher. Her latest project, Swap-O-Rama-Rama, is a clothing swap she created as an alternative to consumerism. Wendy lives in Truth or Consequences, N.M. gaiatreehouse.com

HEADGEAR MIDI CONTROL

Make your own octo-microphone USB/ MIDI controller. By Tristan Shone

Based on my lifelong habit of "beatboxing" melodies and rhythms and essentially songwriting as I walk, drive, or shower, I've always wanted to make a device that would take my vocal mush and output exactly what's in my head, in real time on stage.

Well, I haven't achieved exactly that yet, but I have created an 8-microphone input device that allows me to trigger or control 8 simultaneous sounds from music sequencing software (Ableton Live) as well as output 8 different mic/audio channels of my voice for input into the computer or mixer.

The 2 rows of 4 electret condenser microphones are unidirectional and compartmentalized, so there's little cross-contamination of the audio inputs or vocals. Each microphone's distance from your mouth is adjustable through a custom spring-loaded mechanism, and they're close enough together that simply by turning your head or twitching a bit (much

MAIN COMPONENTS OF HEADGEAR

1. Electret microphones (8) Digi-Key part #AUM-5247L-R
2. Curved stainless steel microphone housing
3. Spring-loaded microphone case cartridges (8) machined in aluminum from my design; you can substitute common hardware.
4. Gooseneck mic-stand attachment
5. Headgear Electronics Rack
» Arduino Duemilanove microcontroller available at makershed.com item #MKSP4
» Arduino ProtoShield containing basic mic-powering circuit
» Mic outputs (8)
» USB hub (optional) for adding additional devices
6. PreSonus FireStudio 8-mic preamp unit or other FireWire mic preamps, for input into computer
7. Computer running sound software (Ableton Live), Arduino IDE, and Serial-MIDI Converter

Photography by Juliana Maschion

Headgear Casing and Template

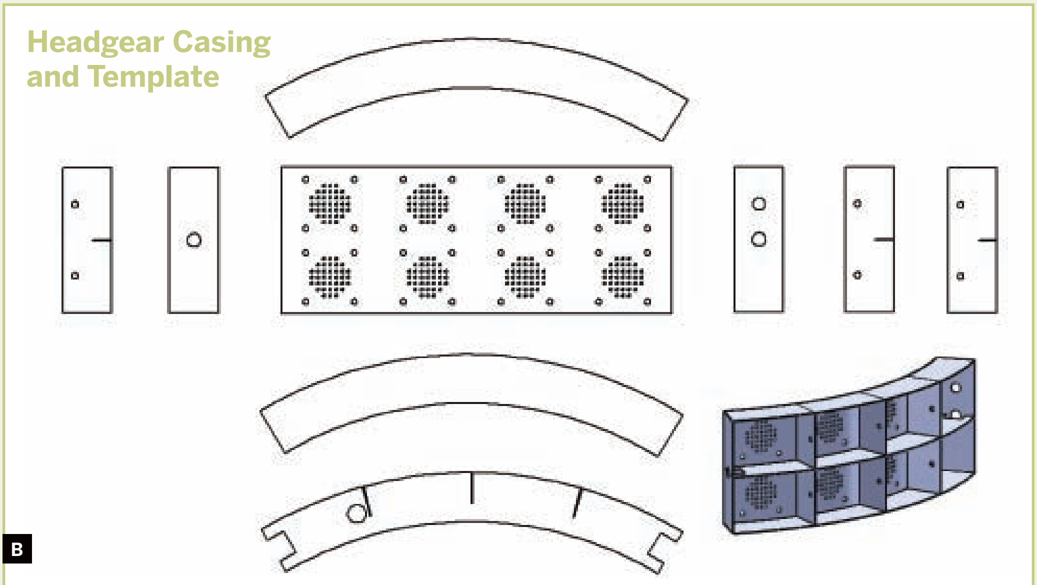


Fig. A: Headgear casing shape. Fig. B: Headgear template example. You can make yours by hand or using software such as Illustrator, SketchUp, or SolidWorks, as shown here.

like a cat following a fly) you can easily place your mouth over any of them.

The brain of the Headgear is the Arduino Duemilanove microcontroller. The entire device (microcontroller and mics) is USB powered and has 8 mono microphone outputs. Since there are only 6 ADC (analog-to-digital converter) inputs on the Duemilanove, only the first 6 mic signals are used for MIDI triggering, but all 8 are live mic signals.

The signal from the microphones is split: it goes to the preamplifier as the audio signal that you hear, and also goes to the analog (ADC) pins of the Arduino. The Arduino converts the signal to serial data to send to a computer, and the computer uses the Serial-MIDI software to convert it into MIDI, which is then used by Ableton Live as a trigger to do whatever you want. The device is programmed to output MIDI commands to Ableton, but can easily be programmed to output OSC commands to communicate with Pd or Max/MSP.

NOTE: Some hard-to-find tools and materials in this design can easily be simplified. For example, the stainless steel cut and drilled with a water jet can be substituted with plastic cut with a razor blade and drilled with a normal drill.

Headgear Casing and Hardware

1. Decide on a shape.

The first and most exciting part of this device (for me at least) is the shape. Since this is a sound controller using your mouth, think about how you want to move, what configuration your body will be in, and what your hands will be doing while you perform.

Design your Headgear based upon the movement and space limitations of your performance. This is the sculptural component of this project, so be creative!

The curvature of the Headgear (Figure A) matches the sweeping path of my mouth as I rotate my head, and the placement of the microphones allows me to basically tilt my head and rotate it ±60° (much like with a harmonica neck brace).

2. Make the Headgear frame.

First, choose your material. I chose stainless steel because it's strong and, when polished, it's not abrasive against the mouth as it glides from position to position.

Second, work out the envelope for the microphone placement. With your body within your self-defined performance limits, put a marker in your mouth and draw on a piece of paper placed

Diagram by Tristan Shone

Fig. C: Headgear cells. Fig. D: Mic cell, showing cartridge and spring mechanism. Fig. E: Electret condenser microphone and custom-designed cartridge.

Fig. F: Electret condenser microphone. The ground lug connects to the casing; the signal lug doesn't. Fig. G: Soldering the electret condenser microphone.

in front of your face as you move your head; this defines the region where your mics can be placed.

Using this parameter, along with the shape you decided on, create your template for the Headgear frame, either by hand or using software such as Illustrator, SolidWorks (Figure B, previous page), or SketchUp. In your template, each mic "cell" should be isolated from the next by horizontal and vertical braces (Figure C).

Also make sure to include small sound holes at the location of each mic, and four #4-40 machine screw clearance holes around each microphone location for attaching the mic cartridge mechanism.

Figure B shows the flattened Headgear shape with the braces and sides. I exported the drawings as *.dxf* files at 1:1 scale ratio and had the parts cut with a water jet.

If you don't have access to a water jet or laser cutter, you can print the drawings out at 1:1 and use them as a template to cut out with a jigsaw and drill. The pieces can then be welded, or bonded with metallic tape or epoxy.

3. Mount the microphones.

Notice how I mounted the electret condenser microphone disk in each mic cell (Figures C and D). A custom mic cartridge (Figure E) was designed and machined to fit the four #4-40×1" machine screws, resting on top of the 4 springs and fastened with #4-40 nuts.

This design allows the distance of the mic from your mouth to be adjusted, which will change your signal/volume level. When mounted in the cartridge, the black foam side of the electret microphone disk faces toward your mouth.

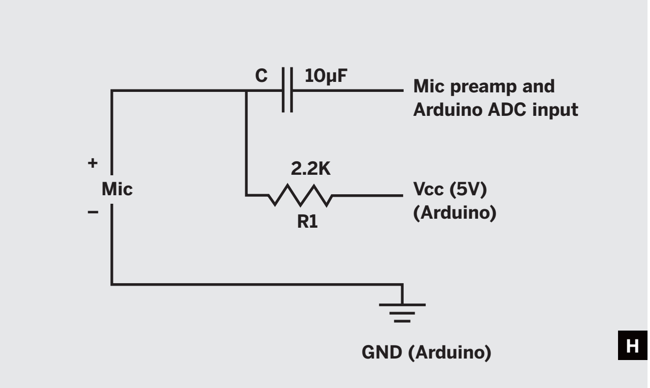
Again, in place of the machined aluminum mic cartridge, you could use rubber bands, foam rubber, or any number of materials that allow you to mount to the 4 screws.

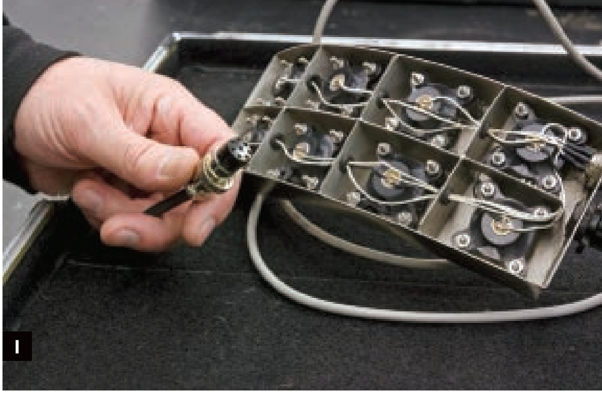
Electronics

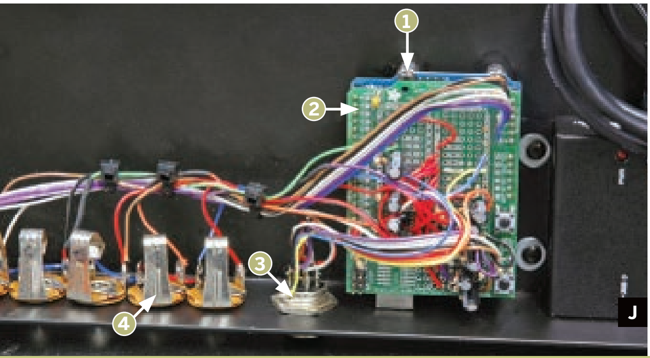
4. Wire up the microphones (Headgear side).

Using at least a 9-conductor cable, strip each wire at both ends. At one end, solder one wire to each of the 8 signal (not ground) solder lugs of the mics. Notice the ground pin on the mic in Figure F is the one connected to the casing. Solder the ninth wire to one of the mic ground pins.

Then, using some extra wire daisy-chain that last ground pin to the next mic ground pin, and so on, until all grounds are connected to the ninth wire and soldered together (Figure I).







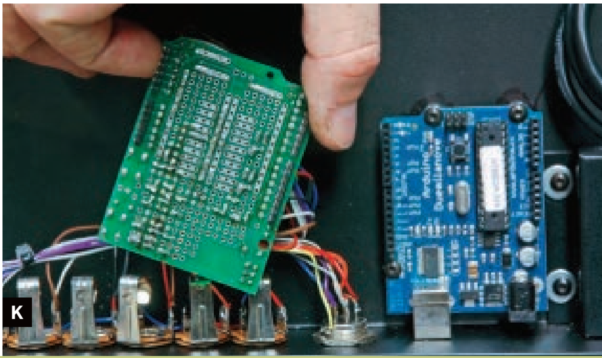


Fig. H: Simple electret mic-powering circuit. Fig. I: The 9-conductor mic cable (8-pin connector with ninth ground pin as the shield). Fig. J: Electronics layout in the rack: Arduino Duemilanove (1), Arduino ProtoShield (2), mic connector from Headgear unit (3), mono mic jacks out to PreSonus FireStudio preamp (4). Fig. K: Electronics layout, with ProtoShield lifted to reveal Arduino Duemilanove.

5. Build the microphone power circuitry.
There are many options for powering and amplifying electret condenser microphones (essentially the same mic in your laptop or in Britney Spears' mobile mic). It comes down to how much time, headache, and money you want to invest. These mics tend to sound tinny to me, picking up every small drop and ping from my mouth — which is what I like about them.

The goal with the Headgear is twofold: to power the mic enough to input a decent line level into the FireWire mic preamp unit (I chose the PreSonus FireStudio because of its 8 mic preamps) and to make sure your max and min output signals are within 0V to 5V for input into the ADC pin on the Arduino microcontroller. This way you get 2 sounds with one mic: your voice and the triggered sound (MIDI volume/expression is controlled by the loudness of your voice or ADC level). Here are the circuits you can use:

Option 1: Simple mic power circuit. Solder the circuit in Figure H onto the Arduino ProtoShield (Figures J and K). Because of the circuit's simplicity, all 8 of the powering circuits can fit onto one ProtoShield. This circuit amplifies the incoming signal using the onboard USB power and outputs to the ADC pin of the Arduino and also the mic preamp of the FireWire device. Without an op-amp, the output is somewhere between 0V and 5V, but not exactly. I compensate for this in the Arduino code simply by setting limits, a quick and easy hack that works!

Option 2: Off-the-shelf circuit. For a more robust solution, create or buy the Amplified Mic op-amp circuit from SparkFun (makezine.com/go/SFcircuit). Soldering it yourself takes up a lot of space, so I recommend buying it, but SparkFun is nice enough to provide the schematic if you don't want to buy their kit. This utilizes a rail-to-rail op-amp that ensures 0V–5V low to high signal.

6. Wire up the microphones (electronics side).
At the other end of the 9-conductor mic cable (the Arduino side), you need to solder each of the (+) mic signal wires into one of the 8 powering circuits created in Step 5, and the single (–) mic wire to ground. Arduino ground, mic preamp ground, and mic ground should all be the same. To reduce hum and buzzing, connect this ground to the rack mount frame.

7. Connect signal to the Arduino and mic preamp. The output of the powering circuit in Figure I (previous page) is both your input signal to your preamp (usable vocal audio) and the analog input to your Arduino ADC pin(s).

NOTE: Since the Arduino Duemilanove has only 6 ADC inputs, only the first 6 mic signals are used for MIDI triggering, but all 8 are live mic signals. An upgrade to the Arduino Mega or some additional circuitry would allow all 8 channels to trigger.

Software

Three pieces of software are required to make the Headgear function: Arduino IDE, Serial-MIDI Converter, and Ableton Live (or the music sequencer of your choice).

» Arduino IDE The Arduino IDE (Integrated Development Environment) software (arduino.cc/en/Main/Software) is a very user-friendly, C-like programming environment.

You need only a small amount of programming to read the ADC pins of the Arduino and then output the MIDI commands to trigger and control sounds; the code can be downloaded at tristanshone.com/soundmachines/headgear.

» Serial-MIDI Converter This software from Spikenzie Labs allows you to convert serial commands coming from the Arduino via USB into MIDI data that's readable by music sequencing software without the need for a MIDI-to-USB adapter.

It's very helpful to be able to both program and power your Arduino, as well as read MIDI, with a USB cable — no adapters or power cables. Download and follow the detailed instructions for setup at makezine.com/go/serialmidi. This software must run in the background while Ableton is open in order for Ableton to recognize the MIDI input.

» Ableton Live Within Ableton Live's preferences, you need to select the device; the Headgear device will show up as IAC Driver, which is set up in the folder Utilities/Mac Audio MIDI Setup.

Once you select it, you can begin to map the Headgear MIDI to any parameters in Ableton, like drums or samples. You might need to play around with the actual MIDI command you have programmed on the Arduino (e.g., `MIDI_TX(149,64,0)`) so as to not interfere with other controllers. In addition to triggering, each of the 8 channels of vocal audio is fed into 8 different audio channels with different effects. Have fun!

Headgear as Harmonica

To use the Headgear as a "harmonica"-style drum machine, I use either the drum machine or the Impulse drum machine in Ableton. Both of these Ableton instruments are essentially samplers where you drop a sound/sample into a slot that's actually a MIDI note.

You'll need to figure out which MIDI notes your samples are on in the Ableton drum machine so that you can output the correct 6 MIDI commands from the Arduino (e.g., middle C is `60`, so choose `60–65`) to trigger 6 consecutive sounds. Once you have each of these 6 microphones triggering from your voice, you'll need to make some adjustments based upon how you'll use it.

If you're controlling drum sounds, to prevent multiple triggers from one voice impulse, utilize the `millis()` command (a real-time timer) in the Arduino code to make sure not to trigger twice within a certain time frame (you can see how I've done this in my code).

With drum or rhythmic samples, you can play around with the mic order so that your head movement is optimized; for example, a configuration of upper left (kick drum), upper left inside (high hat), upper right inside (snare) creates a simple setup for basic beat making. For a more robotic movement, you can set up 4 samples in a row so that your head moves like a typewriter (my preferred setup).

If you intend to utilize both audio and triggering from a mic simultaneously (making a sound that might have an effect applied while triggering), you'll need to play around with the `millis()` timer again in the C code to control how many times you trigger. In this case you might want to also adjust your analog input threshold.

Tristan Shone is a mechanical engineer, sculptor, musician (authorandpunisher.com), and creator of the Drone and Dub Machines sound controllers. Read an interview with him on page 30.

Photograph by Charlotte Williams

DIDDLEY BOW

Build the elemental slide guitar.

By One String Willie

After reading Alan Lomax's excellent book *The Land Where the Blues Began*, I developed an interest in the diddley bow, a primitive one-string guitar rarely heard outside the rural South.

Shane Speal, founder of the current cigar box guitar movement, suggested I get the CD *One String Blues*, which featured nine cuts by diddley bow master Eddie "One String" Jones. The performances were stunning — raw, percussive, and deeply compelling.

After just one listen, I knew I needed to build and learn to play this instrument. On the first track of the CD, Jones describes how he had built his diddley bow; a drawing of his instrument and two photos were included in the CD insert. With this information, I built my first traditional diddley bow.

In the South, the diddley bow is considered an informal practice instrument, built from found or recycled materials. In this article I'll share a process I've refined to quickly build a stable, good-sounding instrument (which I think is more important than taking a long time to build a good-looking instrument).

It only takes about 10 minutes to build a diddley bow if you have all the pieces and tools handy. This version is made from a board with a nail driven into each end, with a piece of steel wire stretched between the 2 nails and tensioned by slipping a small jar or bottle under the wire string and pushing it as close to one of the nails as possible. A small scrap of wood is slipped under the wire and pushed as close to the other nail as possible.

Traditionally, the string is struck in a rhythmic manner with a finger, a stick, or some other implement, and the pitch of the string is altered by using a slide made of glass, metal, or another hard substance. The diddley bow is slide guitar stripped down to its most elemental level.

MATERIALS AND TOOLS

Wire for the string. Get a couple of pieces.
Board, about 3' long for the body
Short piece of pipe, or a sturdy, straight-sided glass jar or some other fairly rigid object for the bridge. Don't use a baby food jar — they're too fragile.
Scrap of wood for the nut
16-penny common nails (2)
6-penny finishing nails (2)
Flat glass bottle, half pint for a slide
½" stick, about 6"–7" long to beat out a rhythm on the string
Hammer and saw
Side-cutting pliers
Combination (half-round) rasp These are round on one side.
Permanent marker

SCALE DEGREE VS. POSITION MARK	
POSITION MARK	**SCALE DEGREE**
Open string	Root note of scale
3	Flatted third of scale
5	Fourth of scale
7	Fifth of scale
10	Flatted seventh of scale
12	Root note one octave higher
15	Flatted third one octave higher
17	Fourth one octave higher
19	Fifth one octave higher
22	Flatted seventh one octave higher
24	Root note two octaves higher

WARNING: If you build a diddley bow, be aware that the wire could snap under tension; in addition, the board and the glass jar bridge are both under compression. Use face and hand protection when tensioning up the diddley bow. Please use good sense when building, tuning, and playing these instruments.

Choosing the Right Wire

The main criterion for the wire is that it shouldn't stretch much when put under tension. The traditional diddley bow string is broom wire, the wire that binds the straws of a broom (Figure A). You can clean off the rust with Nevr-Dull polish.

Music wire (0.032", 0.039", 0.047", 0.055", or 0.056") from a hobby shop is a good substitute; I used it to make the diddley bow for this article. Hobby shops carry 36" lengths, good for about a 27"–30" instrument; for longer diddley bows, you can order 72" lengths from smallparts.com. Note that larger diameters are difficult to bend and cut (try heavier pliers or a Dremel), but sound better.

Galvanized fence wire from the hardware store is a poor substitute because it stretches as you play, which causes the pitch to drop.

Build the Diddley Bow

1. String the wire on the board.

Cut a piece of 2×4 or 2×6 lumber to about 3' long (or about 4" shorter than the length of your string wire). Drive two 16-penny nails into the face of the board about 1" in from each end, angling the nails upward toward the ends of the board.

Wrap one end of the wire around one of the nails for a couple of turns and then around itself. Wrap the other end of the wire around the other nail for a couple of turns, keeping it fairly tight, and then around itself. Now cut off the excess on both ends. Keep the wire close to the board at both ends, and try to get it as tight as you can.

To keep the wire from slipping up on the 16-penny nail once the bridge goes underneath, drive a 6-penny finishing nail into the wood beside the 16-penny nail, and then hammer it down over the wire (Figure B).

2. Install the bridge.

For the bridge, I've used small jars or bottles made of thick glass with cylindrical, not tapered sides, such as jelly jars, instant yeast jars, or hot sauce bottles. A large pipe coupling or an Altoids tin also works well.

Slip the jar under the wire at the center of the instrument, and slide it toward one of the nails, pushing it as far as it will go. Push the jar as close as you can to the nail, and then mark where the jar rests on the board (Figure C).

Slip the jar away from the nail, past your mark, and use a half-round wood rasp to rasp out a shallow groove across the board for the bottle to fit into (Figure D). Slip the jar back so it snaps into the groove (Figure E).

3. Add the nut.

Once the jar is in place, it's time to install the nut. Slip a scrap of wood (about 1"×2") under the string and push it as far as you can toward the other nail.

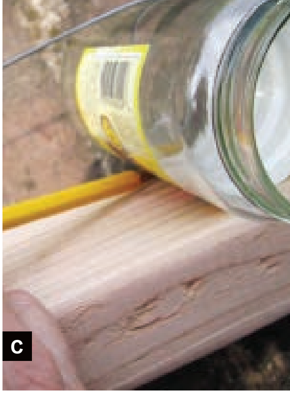


Fig. A: The traditional diddley bow string is broom wire. Fig. B: Drive a 6-penny finishing nail into the wood beside the 16-penny nail, and then hammer it down over the wire. Fig. C: Push the jar as close as you can to the nail, and mark where it rests on the board. Fig. D: Rasp out a groove for the jar to fit into. Fig. E: Slip the jar back so it snaps into the groove. Fig. F: Use a hammer with a dowel to whack the wooden nut into place.

At this point, the wire should sound "bright" when struck with a stick. If it still gives a dull thump, the wire needs to be tighter. Use a tack hammer (or a regular hammer with a dowel) to whack the nut (not the jar!) toward the nail (Figure F).

CAUTION: If you're using a glass jar for a bridge, wrap the whole bridge end of the diddley bow in a towel when tensioning up the wire, in case the jar shatters.

If the string is as tight as it will go with the current block of wood and still sounds dull, try a larger (taller) block of wood to increase string tension. If this doesn't help, use a larger-diameter jar, or restring, getting the wire a little tighter to start with.

4. Make the position marks.

This diddley bow is played slide-style, resting across the knees. The pitch is changed by pressing a glass or metal slide against the string. When playing slide on a new instrument, I rely on visual cues (position marks) to get close to a pitch, and then on my ear to get it exactly. Position marks are similar to fret markers on a guitar. Not every fret has them — they're there to help you know where you are along the string.

Photography by David Williams

You could use an online fret calculator (see makezine.com/21/cbg), set for 24 frets, to mark the string at fret positions 3, 5, 7, 10, 12, 15, 17, 19, 22, and 24. But here's the easy, traditional, low-tech method for laying out the position marks and double-checking them by ear:

Start by measuring the open string length, from the far edge of the wooden nut (the edge closest to the nail) to the top of the bridge (Figure G, following page). From the far edge of the nut measure ¼, ⅓, ½, ⅝, ⅔, and ¾ of this length along the string, and mark the string at these points with permanent marker.

Now check your marks. Hit the string with a stick, and very lightly and briefly touch the string (damp it) with your fingertip at exactly the ½ mark while the string is vibrating. You should hear a chiming sound, which is a higher harmonic of the string. If you lightly damp the string a small distance away from this point, the chiming sound won't occur — you'll simply stop the vibration of the whole string.

If the harmonic is more pronounced when you damp the string at a slightly different location from your mark, this means the original mark is in the wrong location; change the mark so it's at the point where the chiming sound is loudest when you touch the string. Mark the board directly below this point.

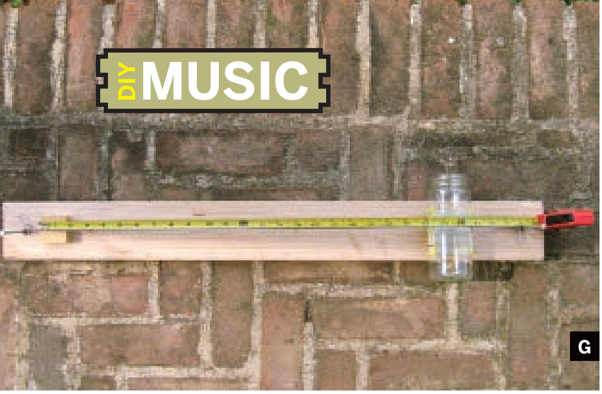


Fig. G: Measure the open string length, from the far edge of the wooden nut (the edge closest to the nail) to the top of the bridge. Fig. H: Going from the nut toward the bridge, number the marks 5, 7, 12, 17, 19, and 24.

Fig. I: Measure and mark positions 3, 10, 15, and 22 at 0.63 times the distance between adjacent marks. Fig. J: Right hand strikes, left hand slides. Here's a trick: use the left hand to stop the string's vibration.

Next, proceed to the ⅓ and ⅔, and then to the ¼ and ¾ marks. Do the ⅝ mark last — the chime will be difficult to hear, but if the rest of the points are marked properly, we can take this one as validated by the others. Going from the nut toward the bridge, number the marks 5, 7, 12, 17, 19, and 24 (Figure H).

Once these are established, proceed to the 3rd, 10th, 15th, and 22nd positions. Measure the distance between the far side of the nut to position 5, multiply this distance by 0.63, and mark the calculated distance on the string up from the lower numbered position (0, far end of the nut). Then mark this on the board. This will be position 3. Do the same between 7 and 12, multiply by 0.63 to get position 10, mark it, and continue between 12 and 17 (shorter still) to get position 15, and between 19 and 24 to get position 22 (Figure I). There are no harmonic "chimes" at these positions.

Play Your Diddley Bow

The position marks form a pentatonic scale over 2 octaves, important for blues and rock. Remember that there are notes *between* the marks (a diatonic scale would be: open, 2, 4, 5, 7, 9, 11, 12, etc.).

Pick out a song you know well, and find the notes for it on the diddley bow. Work on finding one note at a time, then one phrase at a time, and finally put them together as a song. When working out a song, if the open string doesn't work for you as a starting place, try starting on position 7. With practice, you'll be able to play almost any kind of music.

One of the secrets of rhythmic playing is using *both* hands to develop rhythmic drive, by using the left hand to stop the vibration of the string. The stick in the right hand beats out a rhythm as a timekeeper, while the left hand touches the string at different points in the rhythm to *stop* the notes from sounding, allowing a percussive "thump" to sound instead — this is a powerful technique.

These homemade instruments bring back the fun I had teaching myself to play guitar many years ago. I hope they give you the same pleasure!

+ More on diddley bows, wire, and playing, plus concert video, a discography, and a bibliography, can be found on my website, onestringwillie.com.

One String Willie (onestringwillie@verizon.net) is the stage persona of Philadelphia-area musician David Williams, a member of the homemade music community and a recognized authority on diddley bow playing and history.

Photography by David Williams (G–I), and Charlotte Williams (J)

WINDING YOUR OWN

Build a homemade electromagnetic guitar pickup. By One String Willie

Photograph by Sam Murphy

When I first started building homemade instruments, I used a piezoelectric buzzer from RadioShack as a pickup (see onestringwillie.com for details). But while it's cheap and simple, the piezo transducer has downsides: it has a low signal output, it picks up a lot of handling noise and can go into uncontrollable feedback at high volume, and it sounds thin and not nearly as authoritative as an electromagnetic pickup.

If you want to crank it up until it sounds like you really *do* have possession over Judgment Day, an electromagnetic pickup is the way to go. In this article, I describe how to wind your own electromagnetic guitar pickups on sewing machine bobbins.

1. Wind the wire onto the bobbins.

Find the end of the wire, and use a small piece of blue masking tape to stick it to the end of the spool so you don't lose it. 42 AWG magnet wire is only about 0.0025" in diameter, not much different than a human hair. Set the spool aside.

Learn how to use your sewing machine's bobbin winder. Near the bobbin winder post is a small metal finger called a brake that pushes on the bobbin when it gets full of thread (Figure A, following page). You don't want the brake to push on your bobbin of wire, so I suggest you remove the brake before winding your pickups. Typically the brake is held on with a small screw and nut, and the nut is on the inside of the machine. Make sure you can retrieve the nut *before* you try to remove the brake — don't lose the nut into the machinery!

Set up the sewing machine at the back of your work table. Put the foot pedal on the table in front of the machine.

Build a wooden platform that sits on the table at the height of the top of the sewing machine, a little

MATERIALS AND TOOLS

Sewing machine with Singer Class 15 plastic bobbins
  The central hole varies slightly with bobbin type; Class 15 fits the magnets below.
Cylindrical neodymium magnets, ¼" diameter, ½" long wondermagnet.com
42 AWG single-build copper magnet wire stewmac.com
Painter's blue masking tape
Emery paper, 600-grit
Scrap wood and wood screws
Heavy wire, about 2'
4oz–5oz weight e.g. stack of quarters, large washers
1qt metal paint can empty and clean
1lb paraffin sold in grocery stores for canning
4oz beeswax sold in craft stores for making candles
½" waterproof adhesive tape sold for bandages
Brass escutcheon pins
Scraps of very thin plywood and scrap of wool felt
1' length of audio cable with braided outer shield such as RadioShack part #278-513
Phono jack
Digital volt-ohmmeter
Magnetic compass
Soldering iron and acid-free solder
Saw, screwdriver, scissors, ruler, razor blade
Silicone caulk or hot glue
Pot of hot water


A


B

lower than the bottom of the bobbin winder, and hanging over the front edge of your work surface (Figure B). Round off the front edge of the platform and cover it with felt. The spool of magnet wire sits underneath this edge on the floor.

The wire comes up from the spool, over the felt-covered edge of the platform, and onto the bobbin, allowing the wire to feed straight onto the bobbin. (A length of yarn is used in Figure B to clearly show the wire path.)

Before threading the wire onto the bobbin, tape it to the platform and lightly rub its free end with 600-grit emery paper for a few strokes to remove the insulation, so that you can solder it later.

Thread about 2" of wire through the small hole in the top of the bobbin, and tape it in place on top with a very small piece of blue masking tape (Figure C). Near the felt-covered rounded edge of the platform, place another small piece of felt on top of the wire and then place a small weight on top of the felt: the wire is sandwiched between 2 pieces of felt, and the weight provides constant resistance for the bobbin winder to pull against (Figure D).

For me, weights between 50g–200g (2oz–7oz) worked well. Put a few very small pieces of masking tape somewhere on the platform so they'll be available when you cut the wire.

Using your left hand to control the foot pedal, carefully wind the wire onto the bobbin, moving it up and down slightly with your right hand to distribute it fairly evenly. There's a narrow rim on the bobbin, and I fill it to this point.

When the bobbin is filled (Figure E), tape the long wire to the platform and use emery paper to strip the insulation from it, rubbing toward the bobbin. Cut the wire in the middle of the stripped area, holding onto the wound bobbin with your fingers.

Take the bobbin off the winder, holding the wire coil in place, and wind the remainder of the wire onto the bobbin toward the top, leaving a tail about 2" long. Remove the tape from the original wire end on the top of the bobbin, and tape the tail onto the edge of the top, leaving the center hole open (Figure F).

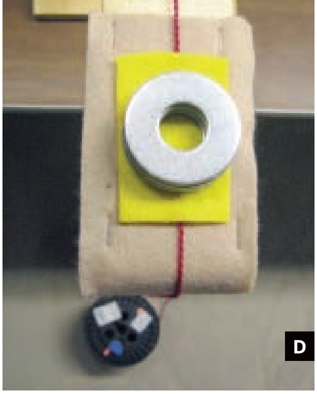
Repeat these instructions to wind as many bobbins as you have patience for — the wire is very fragile, and the pickups are easy to damage until they're mounted, so it's good to have spares.

2. Check the resistance of your windings.

Use a multimeter to check the resistance between the 2 ends of the wire on the bobbin. In 8 bobbins,

Photography by David Williams

C



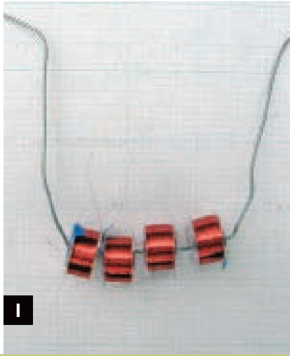
D

E

F

G

H



I

Fig. A: If you remove the bobbin brake, be careful not to lose the nut in the sewing machine! Fig. B: The wire comes up from the spool, over the edge of the platform, and onto the bobbin. Fig. C: Thread wire through the hole in the top of the bobbin. Fig. D: The weight provides friction resistance. Fig. E: Bobbin filled with wire. Fig. F: Tape wire to the top of the bobbin. Figs. G and H: Melt wax in hot water — outside. Fig. I: Bobbins ready to dip in wax.

I got an average resistance of 1,360 ohms, with a variance of 3%. For 3 of the other bobbins, I allowed the wire to go above the bobbin and it got caught on the tape; 2 were useable (but well below the resistance of the others) and one was not.

3. Pot your windings in wax.

Pot the pickup assemblies in hot wax (by weight, 80% paraffin, 20% beeswax). Potting reduces microphonics — sounds made when the wires in the pickup pick up mechanical vibrations from the guitar or sound system.

WARNING: The vapors this wax mixture gives off when hot are highly flammable. To minimize fire hazard, do this step outside. Don't allow anyone to smoke near the can of hot wax.

Outside the house, I put 16oz solid paraffin and 4oz solid beeswax into a clean, empty 1qt paint can. Inside the house, I boiled water in a pot. Then I took the pot outside, placed it on a cork pad, and put the can of wax in the pot (Figure G). While it warmed, I went back inside and heated a second pot of water. I continued alternating pots of near-boiling water until the wax was melted. I stirred the melting wax with a wooden paint stirrer until it was completely liquid. The point here is that the wax was outside, and the water was heated inside the house, so the wax was never near the fire (Figure H).

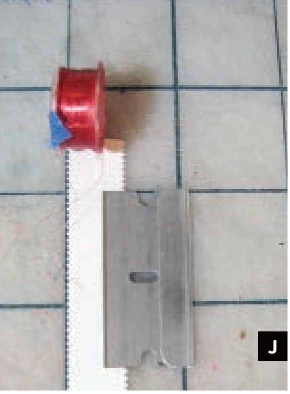
Thread a loop of heavy wire through the center holes of the wound bobbins (Figure I) and dip them into the liquid wax. Let them sit in the wax until bubbles stop coming out of the windings, indicating that wax has penetrated the windings. Pull the bobbins out and let them air-cool.

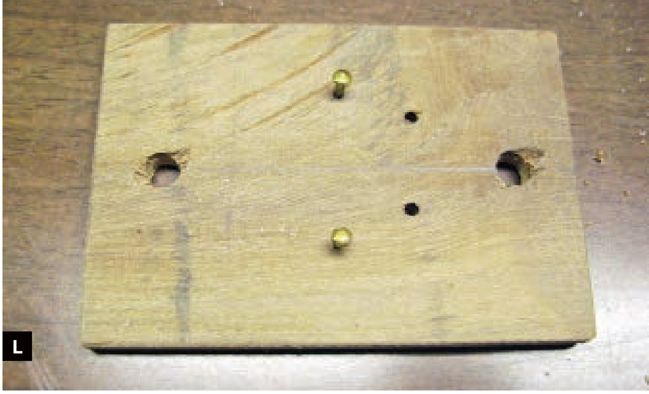
4. Add magnets to make pickups.

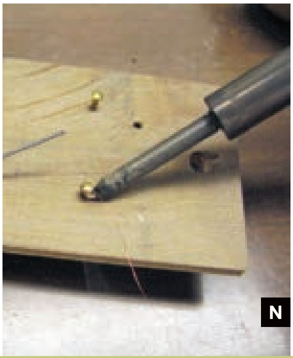
Cut a piece of waterproof adhesive tape about 2½" long and about 9mm wide to fit between the sides of the bobbin. Using a metal ruler and razor blade makes a neat job of it (Figure J, following page).

Wrap the wire coils with the tape to protect them from damage, and try to get both wires on the same face of the bobbin. Write the resistance of the coil on the tape with permanent marker.

Use the magnetic compass to mark the polarity of each magnet (Figure K), and then insert the magnet into the center hole of the bobbin. Make sure the magnetic poles for each magnet are all pointing in the same direction with respect to the side of the bobbin where the inside end of the wire comes out.







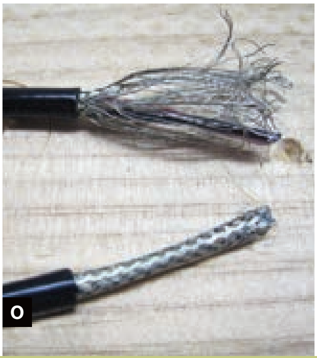


Fig. J: Prepare tape to wrap around bobbin. Fig. K: Use a magnetic compass to find the polarity of each magnet. Fig. L: Pickup mounting board with brass escutcheon pins. Fig. M: Bobbin mounted with a dab of adhesive.

Fig. N: Solder bobbin wires to pins. Fig. O: Prepare a short length of shielded cable by removing a bit of insulation from each end. Fig. P: One end of the cable was soldered to the pins and the other to the lugs of the phono jack.

(The exception to this is if you're preparing a pair of coils for a humbucking pickup — see Going Further.)

5. Wire your pickups.

To mount the pickups for wiring, I drilled 2 small holes in a piece of very thin plywood, inserted 2 brass escutcheon pins on the underside of the plywood to use as soldering posts (Figure L), passed the magnet wire leads through the holes, and mounted the bobbin using a dab of hot glue or silicone caulk (Figure M).

After carefully sanding the coating off the ends of the wire, I soldered the leads to the escutcheon pins (Figure N). I prepared a short length of shielded cable by cutting a couple of inches of insulation off each end, separating the strands of the shielding (Figure O) and cutting off all but a dozen or so strands at each end, and then twisting the shielding strands together with the stripped black conductor on each end. (If you use plain wire instead of cable, keep the wire lengths short from the connecting posts to the soldering points on the ¼" phono jack.)

One end of the cable was soldered to the escutcheon pins and the other onto the lugs of the phono jack (Figure P). The black conductor/shielding was soldered from the bobbin's wire to the lug that connects to the photo plug's barrel, not its tip. Use the digital volt-ohmmeter to make sure the connections are good.

6. Mount your pickups and play!

You can work out for yourself how to attach this assembly to your instrument, but remember that the fine wires from the coil break easily if the coil is jarred loose from the plywood — make sure you mount it so the coil and wires are protected.

One pickup will be good for 1 or 2 strings (mounted directly beneath or between the strings, respectively). For more strings, wire the pickups in series, with the outside wire of one pickup connected to the inside wire of the next.

Going Further

With this basic pickup winding technique in hand, you can experiment with different configurations. To make a humbucking pickup, mount 2 coils with similar resistances to go under one string, joining their 2 inside wire ends together, and inserting the magnets into the 2 coils with opposite polarities. The free outside ends of the coil wires will be connected to the 2-conductor shielded cable.

iPHONE SCREEN REPAIR

Replace the broken glass of an iPhone 3G.

By Morten Skogly

I dropped my iPhone and broke its glass touchscreen. It didn't take much; just a 40cm drop onto asphalt, and my lovely iPhone 3G was transformed into a cobweb of sadness.

Apple doesn't repair this, at least not in Norway, where I live. There's Dr. iPod (dripod.no), who specializes in iPhone repairs, but he has so many customers that he now does repairs only for people who come to his shop, which is in Oslo, 550km away from me. But I like fixing things, so I replaced the screen myself. And it wasn't even that hard.

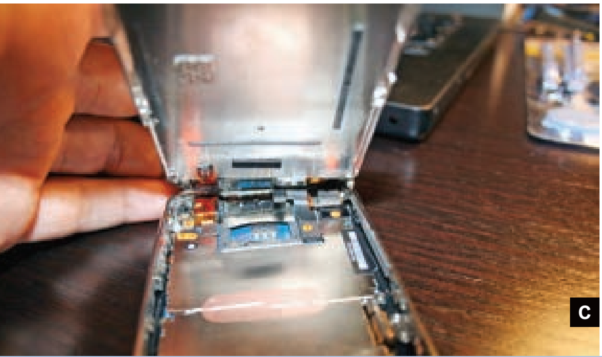
1. Remove the SIM tray and screws.

Find a paper clip and stick it into the tiny hole at the top of the iPhone to pop out the SIM card tray. Unscrew the 2 screws at the bottom of the iPhone, near the charger port (Figure A, following page). Congratulations, you've just voided your warranty!

Photography by Morten Skogly

MATERIALS AND TOOLS

iPhone with broken glass touchscreen broken, but LCD still works
iPhone glass touchscreen replacement part #16101 from Deal Extreme (dealextreme.com), $24
Double-sided tape You can buy pre-cut "3G Front Panel Adhesive Strips" from iFixit (ifixit.com) or you can cut your own, like I did.
Heat gun or hair dryer A heat gun gives you more control.
Paper clip aka SIM tray removal device
Scissors, tweezers, newspaper
Sharp knife or 2 with a thin blade, or small suction cup to pry loose the screen from the frame
Tiny Phillips screwdriver Deal Extreme #11839, including some useless plastic tools that won't help you at all, is $3.
Box or something else to keep the tiny screws in
Cotton swab and electronics cleaner or acetone or nail polish remover



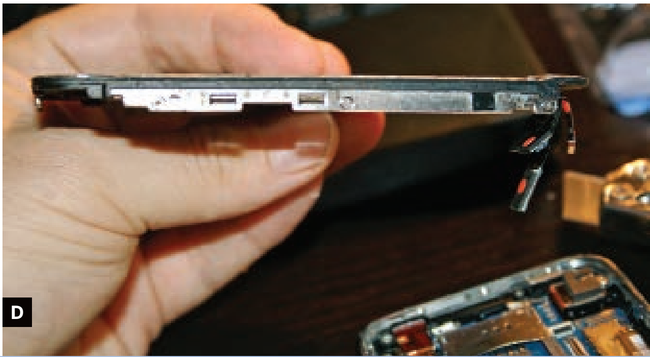


Fig. A: The first 2 screws to unscrew flank the charger port. Fig. B: Dig in with a sharp blade to pry away the touchscreen assembly, or use a suction cup.

Fig. C: Touchscreen and frame pried away. Fig. D: Touchscreen and 3 cables detached.

2. Gently pry the frame loose.

Place the knife blade (the thinner the better) in the crack between the black rubber seal and the silver plastic frame, then pry away the frame (Figure B). You might have to use a little force, but don't overdo it. You can also use a small suction cup.

I had 2 iPhones, one to practice with and one to actually fix, but you probably have only one chance at this. So be careful not to damage the black rubber seal or the frame itself. On one of my iPhones, the screen came loose pretty easily, but on the other I had to try several times to get the blade far enough down to produce the leverage I needed. This caused a little damage to the rubber edges of the frame.

When you get the crack wide enough using the knife, you can wedge in a guitar pick or another knife to gently widen the gap. The screen and frame should lift up fairly easy then (Figure C).

3. Disconnect the 3 cables.

Use the knife to disconnect the cable connectors, conveniently labeled 1, 2, and 3, that are located toward the top of the phone. Be very careful and don't use too much force. Connectors 1 and 2 lift straight up, but 3 is a bit different. On my iPhone there's a tiny black flap that holds cable 3 in place, but on some iPhones it's white. Gently lift this flap up and the last cable should slide out easily.

You have now completely separated the touchscreen assembly from the body of the iPhone (Figure D). Sweet! Now put it all back together again before continuing, so that you know how it should feel when you do it for real later. No, really, I mean it!

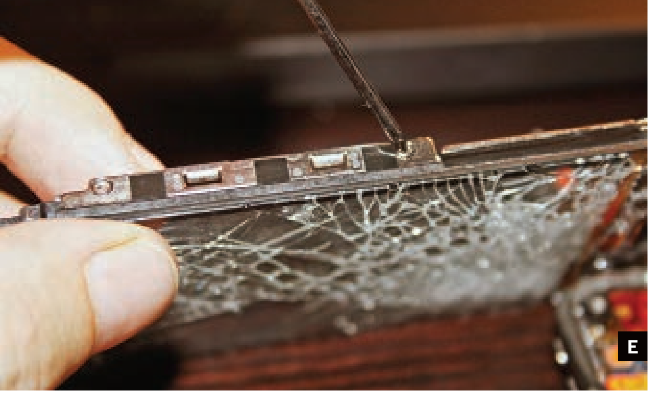
4. Separate the LCD from the frame.

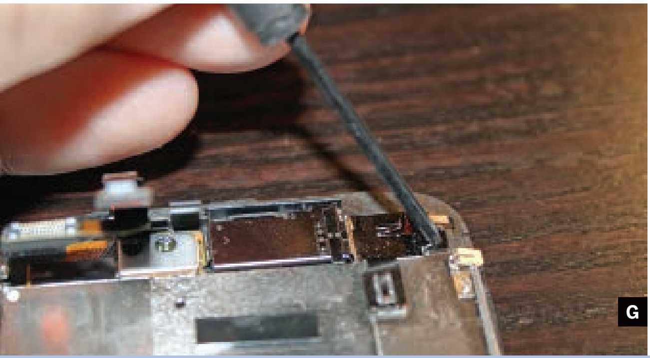
There are 3 tiny screws on one side of the frame, and 2 on the other side, hidden underneath a piece of black tape. Unscrew all 5. Then there's one more screw to remove, and I promise it's the last one. It's located toward the top. This screw and the 5 screws from the sides are all the same size, so you don't have to worry about mixing them up (Figures E, F, and G).

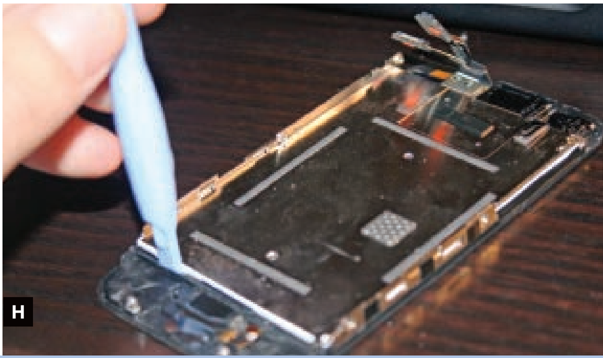
Put your knife or similar thin instrument underneath the LCD. Gently lift the LCD away from the frame, being careful not to break it (Figure H). You should be able to slide the LCD gently toward you until it's completely separated from the frame.

5. Use a heat gun to remove the broken glass.

The glass is fastened to the frame with clear







Figs. E, F, G: Unscrew 5 tiny screws on the sides and top of the frame to separate the LCD touchscreen from its frame. Some of these screws are hidden under pieces of tape.

Fig. H: Pry the LCD away from its frame very gently, taking care not to break it.

double-sided tape at the top and bottom, and some kind of silicone or rubber cement around the edges. You want to heat the glass and underlying adhesives just enough to let you pry or tweeze off the glass, but not so much that you melt the plastic or rubber.

Depending on how broken your screen is, you might be able to remove the entire panel in one fell swoop. More likely, you'll have to remove it in pieces.

Put the frame and glass on newspaper, glass side up, and use a heat gun or hair dryer, experimenting with distance and time for loosening the tape (Figure I, following page).

I found that heating the glass in short bursts let me use my knife (and later a pair of tweezers) to remove all the glass fragments one by one. It took a little under half an hour.

My glass had already loosened on the sides, so I started there. I removed the middle part quite easily, even without a heat gun. But the glass at the top and bottom of the panel was really stuck.

NOTE: Try not to melt the plastic or rubber, or warp the frame with the heat. I warped my frame a little bit, but was able to fix it by heating it a little and bending it back into shape.

6. Clean the frame.

Use a knife or flathead screwdriver to scrape away as much as you can of the remaining adhesive around the edges. Get the surface as clean as possible, and at least remove anything loose. I used a cotton swab and some electronics cleaner spray, but you might also try acetone or nail polish remover (Figure J).

7. Cut the tape strips.

The strips of adhesive film at the top and bottom are shaped to fit around the speaker, sensors, and other electronics. If you don't use pre-cut adhesive strips, you can cut clear, double-sided tape to fit. You basically want to cover as wide an area as possible.

My replacement front panel was protected with a piece of translucent plastic that fit it perfectly. To cut the outlines of my tape strips, I temporarily stuck this plastic onto the tape's backing (Figure K), and cut around the shape with scissors, making sure to avoid touching the sticky side inside the outline.

The top section had more intricate shapes to cut out. For this, I put a plastic bag over the top of the frame and used a permanent marker to color the pieces I had to cut out. Then I taped this plastic-bag template on top of a piece of double-sided tape, and went bananas with the scissors (Figure L).

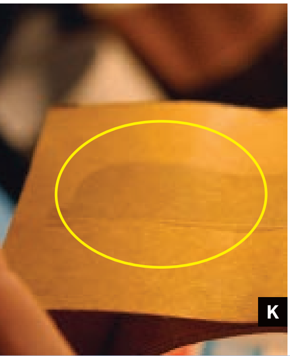


Fig. I: Separating the broken glass from the frame after heating. Fig. J: The frame after removing the glass and the old adhesive, and cleaning it with acetone or electronics cleaner spray.

Fig. K: My iPhone's bottom strip template placed on double-sided tape. Fig. L: My carefully cut-out strips of tape in place on the frame. Fig. M: The repaired iPhone with its shiny new replacement screen.

8. Put in the new front panel.

Put the tape in place on the frame and press down hard for a while. Then peel away the backing. Wash your hands or wear gloves to avoid staining the new glass panel, especially on the inside. Remove any protective plastic covering the glass on the inside, but leave the plastic on the front side.

Place the lower part of the panel in the frame, aligning it perfectly with the lower edge of the frame. Carefully lower it down. Make sure the cables connected to the panel don't get stuck on the tape, and use your fingers to make them go under the frame.

The tape is sticky, but you'll be able to move the glass back and forth a bit to adjust its position in the frame. When you're happy with its placement, press it down hard. Then add pressure on one corner at a time, for about 20–30 seconds, allowing the glass to fasten. You want the glass as deep in the frame as possible. (I felt a little lazy and didn't do this step properly, so my new glass is raised slightly higher than the original.) Voilà, the hard part is done!

9. Reassemble your iPhone, good as new!

Just follow the disassembly steps in reverse. First fasten the LCD with the 6 screws, then attach the 3 cables. One cable runs in a loop, which you need to curve downward, pointing toward the Home button; otherwise this cable will get in the way of the SIM tray. Be careful when reattaching the cables; if you apply too much pressure and break the cables or connectors, you're out of luck!

When the 3 cables are properly connected, turn on the iPhone and test it to see if everything works, before you press the glass and frame completely back in place. (Otherwise you might need to use the knife again to lift off the frame, risking more damage to the frame.)

Now go forth and brag to all your friends, and feel pride in a job well done and money and environment saved (Figure M)!

+ For a helpful video, source tutorial, and a Norwegian version of this article, visit makezine.com/22/diyworkshop_iphonerepair.

Morten Skogly is a cheerful man, even in the dark. He makes things to impress his wife and kids. See more of his DIY stuff at pappmaskin.no and find him on Twitter at twitter.com/mskogly.

HOME PERFUMERY

Extract fragrances from your favorite plants, using steam. By Sean Michael Ragan

This all started when Mom was exposed to radiation and developed a super-power. Seriously, at 58, my mother was treated for cancer with injections of radioactive iodine. When it was over, her cancer was gone, but she'd developed an unnaturally acute sense of smell, which seems to be permanent. She soon became fascinated with perfumery and aromatherapy, and one day asked me, "How do you capture a natural fragrance?"

The trick is called steam distillation, and it's little known today because the fragrance industry has replaced the independent perfumer, who used to sweat in solitude over a bubbling basement still. But in 18th-century France, the perfumer's knowledge of steam distillation amounted to a kind of practical alchemy — the ability to capture a beautiful, ephemeral sensation and preserve it for sale.

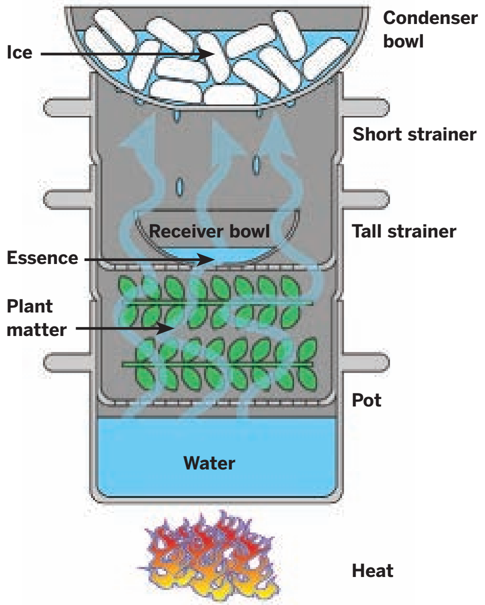
Here we extract the earthy scent of rosemary,

MATERIALS AND TOOLS

- Stainless steel pot
- Integral stainless steel strainer to fit the pot
- Additional stainless steel strainer(s) (optional) to fit the pot
- Raw plant matter Here I use 4" sprigs of fresh rosemary, 160 total.
- Small stainless steel receiving bowl to fit inside the pot
- Large stainless steel condensing bowl of a larger diameter than the pot
- Jars
- Hot pad
- Pliers or kitchen tongs
- Pruning shears
- Ice
- Stove
- Oven mitts
- Eyedropper or turkey baster (optional)

Photograph by Sam Murphy

VapoShrub Diagram



but almost any fragrant plant should work well for this project. The technique is simple: steam rises through a strainer full of plant matter, vaporizing volatile oils and other fragrant compounds, which condense on an icy bowl and drip into a small receiving bowl. Start your essence!

CAUTION: Do not use glass cookware in this project unless you understand how to prevent breakage due to thermal shock. Even borosilicate glass can shatter explosively if heated or cooled too rapidly. Also, be very careful to avoid steam burns while inspecting the still and/or emptying the receiving bowl.

1. Choose your plants.

Decide what kind of fragrance(s) you would like to extract. Generally, the stronger your plant matter smells to begin with, the better. Rosemary, lemon verbena, vanilla, scented gardenia, lavender, and wild rose are just a few of the many possibilities.

2. Prepare your plants.

In preparing your plants, there is a tradeoff between the need to pack as many plants into the still as possible and the need to avoid any processing (such as drying or grinding) that releases the plant's fragrances prematurely.

Fresh, whole plants are best if you have a large still with plenty of room. Dried whole plants are commonly used. Grinding is generally not recommended. We compromised by gently stripping the leaves off fresh rosemary sprigs with our fingers, as shown in Figure A.

3. Assemble your still.

Set the pot on the stove and fill it with water to just below the bottom strainer when it's in place (Figure B). Tap water is fine. Then put the strainer in place.

4. Load the plants.

Fill the bottom strainer with an even, loose layer of your plant matter. You may compact the plants a bit, but be sure to leave them loose enough to allow steam to pass through from below (Figure C).

5. Insert the upper strainer(s) (optional).

The upper strainer provides a level resting surface for the small receiving bowl, which makes it easy to insert and remove even while hot.

I think of a layer of plants as a "stage." The diagram (above left) shows only one stage, but in fact you can have as many stages as you can find strainers to fit your pot (Figure D). The only limit is their structural stability — don't pile them high enough to tip over!

6. Position your receiving bowl.

The small receiving bowl sits on the bottom of the uppermost strainer. If you have only 1 strainer, you can just set the bowl on top of the plants, or you can clear a space in the plant layer for the bowl to rest. Just make sure that it's centered in the pot, and as level as possible (Figure E).

7. Drop in the condenser.

Fill the large condensing bowl generously with ice and position it in the opening of the top strainer, as shown (Figure F). Make sure that it's level and centered over the receiving bowl. Your still is complete (Figure G). I named mine the VapoShrub.

8. Extract the fragrance.

Set the burner to medium-high heat and bring the water in the pot to an even simmer. I find that I can judge by the sound of the simmering water. But if

Illustration by Sean Michael Ragan

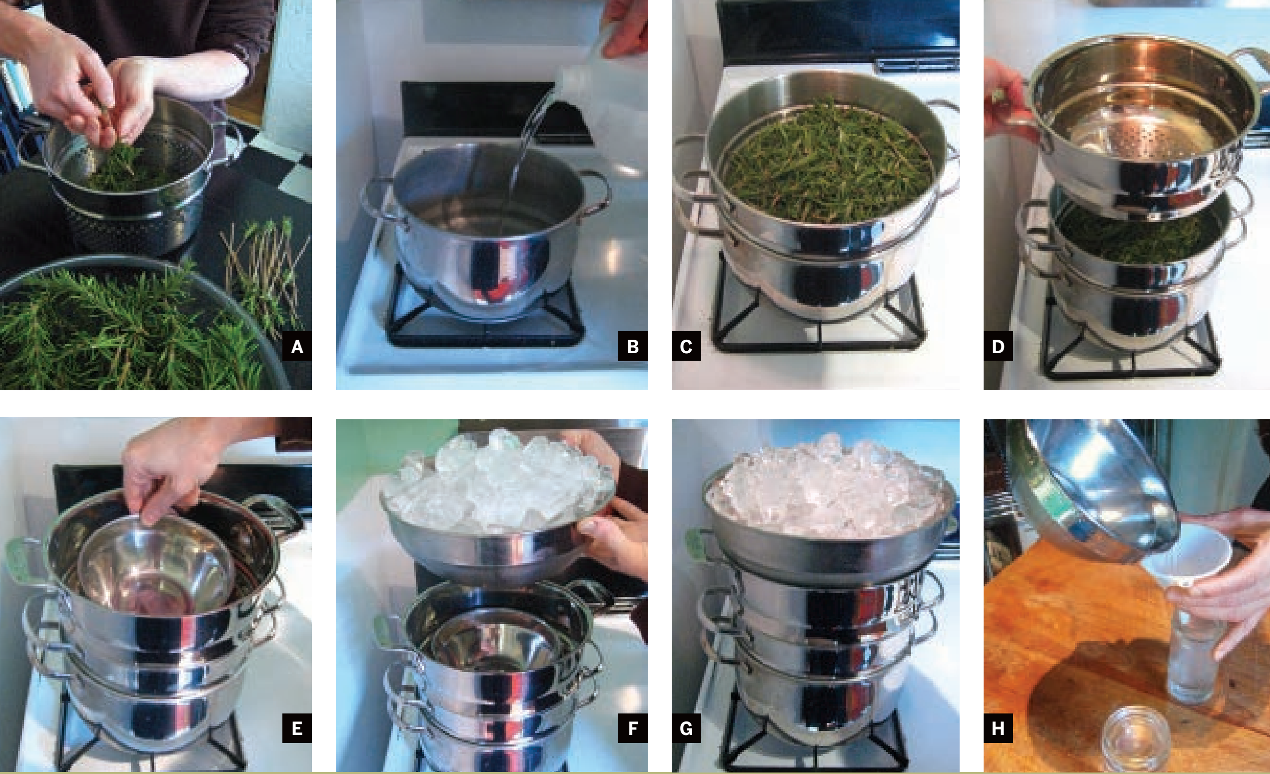


Fig. A: Gently strip the leaves off the rosemary sprigs with your fingers. Fig. B: Fill the pot with water. Fig. C: Pack the plants loosely to let steam pass through from below. Fig. D: Add as many stages as you like. Fig. E: The receiving bowl must be centered and level. Figs. F and G: Place the ice-filled condensing bowl over the receiving bowl. Fig. H: Pour the contents into a different container each time you harvest.

you need to lift off the bowls and strainer(s) to check visually, it won't hurt anything as long as you remember to protect your hands with oven mitts against possible burns from escaping steam.

The boiling water produces steam, which passes through your plant material, where it collects volatile fragrance compounds before rising to the top of the pot. There, it encounters the cold outer surface of the large bowl and condenses, with its extracted volatiles. Condensate flows down the surface of the bowl and accumulates at its lowest point, from which it drips into the receiving bowl. Depending on how much material you extract and the particular distillation conditions, the contents of the receiving bowl may form a clear floral water, a cloudy emulsion, or separate layers of water and oils.

9. Collect the fragrance.

Check on the distillation periodically to empty the small receiving bowl. Be wary of steam burns when you remove the condensing bowl, and don't try to handle the receiving bowl with bare hands. Use pliers or kitchen tongs to grasp the receiving bowl by its rim, lift it out of the still, and pour off into a jar (Figure H).

Each time you empty the bowl, use a different container so that you can compare the smell and appearance of each fraction. This will help you decide when the distillation is complete, and will prevent diluting the more potent, earlier fractions with the later ones, which will be weaker.

If your distillate has a layer of oil floating on top, congratulate yourself: this is the essential oil of your plant material. Skim it off with an eyedropper or turkey baster. It will keep indefinitely.

If there's no oil, or not enough to separate, don't despair. The watery herbal distillate that you've produced, also known as a hydrosol or floral water, is also a valuable commodity. It should keep for a long time in the refrigerator, or you can dilute it with 1 part in 10 of strong rubbing or grain alcohol and store it in a cool, dark place.

Fragrance Uses

Essential oils can be used to scent homemade soaps, lotions, or candles. Drop a cup of floral water into your bathwater for a scented bath, or heat some in a vaporizer for aromatherapy. Mom adds some to her humidifier, or to a dishcloth that she tosses in the drier to scent the laundry. Experiment!

Sean Michael Ragan is a chemist, writer, and artist living and working in Austin, Texas. seanmichaelragan.com

Photography by Abby Wiltse

DIY

HOME

BRILLIANT BUCKLES

Make easy belt buckles with casting resin and your favorite art. By Jenifer Bryan

Personally, I prefer art that has a function other than hanging on a wall. I look for various ways to incorporate my photographs and collages into everyday items — items that act as a vehicle to transport images to the outside world. I've created mobile exhibits with pendants, rings, purses, business card cases, and my favorite accessory, belt buckles, all with the help of resin, a very simple and versatile medium.

Most resins consist of two parts — the resin and a hardener — that when mixed together cause a chemical reaction that cures the resin to a durable finish. Some types of resin require only a few drops of hardener, while others need equal parts hardener and resin.

Resin is really easy to mix and use, and most projects take only a short time to complete (not including the curing time). Making these resin belt buckles has become an addiction of mine, which I will now share with you.

WARNING: Resin produces some nasty-smelling fumes and can irritate the skin. Work in a well-ventilated area and wear protective gear such as a mask, gloves, and eye protection. Cover your work surface with parchment paper to protect it.

1. Find and prep the image.

1a. Find or create an image that you like — anything goes, but make sure it's a horizontal image so that it looks good in the belt buckle. You can find images from magazines, old children's books, leftover wallpaper, and photographs (I wouldn't use the originals), or create something new with paint, ink, or your favorite image software.

Photography by Brianne Corn

MATERIALS AND TOOLS

Belt buckle blank I used a nickel-plated blank from tandyleatherfactory.com, item #11739-01. Can be attached to any 1¾"-wide or smaller snap belt.
Two-part casting epoxy (resin and hardener) I used EasyCast by Castin'Craft.
Latex gloves, face mask, and eye protection
Mod Podge any type, to glue and seal your image
Disposable 1oz medicine cups (3) to measure and mix the resin
Craft sticks (2) to stir the resin
Parchment paper to protect your work surface
Craft knife and straightedge, or scissors
Photograph or other image
Clear protective spray such as Krylon Preserve It
Soft paintbrush
Scrap of metal, cardboard, foam, leather, or wood for leveling the buckle blank before pouring
Drinking straw
Small bowl or container to use as a protective cover while the resin dries

OPTIONAL:
Glossy photo paper
Image editing software and inkjet printer
Baby wipes to clean up resin while in liquid form

1b. The buckle blank used in this project has an interior space that measures 2⅝"×1⅞", or 2.625"×1.875". If the image is digital, resize it to those dimensions. Make sure its resolution is at least 300dpi, and print it on good-quality glossy photo paper with your inkjet printer.

1c. In a well-ventilated area, spray the top of your image with a clear protective spray and let it dry. Ideally, you should spray and dry your image a few times before moving on.

1d. Cut out your image with a straightedge and a craft knife, or scissors if you have a steady hand. Check its dimensions against the buckle blank; you may need to trim it to make it a precise fit. It's a good idea to print extras just in case there's a trimming mishap. Once it fits nicely into the blank, remove the image and set it aside.

2. Adhere the image.

2a. With your brush, coat the interior of the buckle blank with Mod Podge, making sure there is even coverage (Figure A, following page).

2b. Place the image in the buckle blank and use your finger to gently press it down and smooth it out. Move from the center toward the edges of the image to try and remove as much air from under the paper as possible (Figure B).

2c. Brush a thin layer of Mod Podge over the image, paying special attention to the edges. The purpose of the Mod Podge is to seal the paper into the buckle blank completely, trapping any stray air bubbles so they don't come back to haunt you later. Without a vacuum chamber, this is the most effective way I've found to control random air bubbles.

TIP: The brush marks will disappear once you pour the resin, but try to avoid getting the Mod Podge on the metal — it will look milky once the resin cures. You can scrape any excess Mod Podge off the buckle blank with a fingernail after it dries. Just be careful to avoid scratching the image or peeling the edges up.

2d. Let the image dry overnight, or place the buckle in an oven at 225°F for 15–30 minutes, before moving on to the next step.

3. Mix the resin.

3a. Before proceeding, read all instructions included with your resin. Some brands recommend different mix times, and most work best at room temperature. I based the steps in this section on my experience with Castin'Craft's EasyCast resin.

NOTE: Like many casting resins, EasyCast is only good for 6 months from the manufacture date. It won't cure properly if it's old, so when you buy new stock, mark the bottles with the date, and test it before doing an important project if you're getting close to the 6-month mark.

The medicine cups I use have several measuring increments. I use drams because they're simple and they work for my projects, but you can use whatever measurements you like so long as you measure equal parts resin and hardener. Some artists use a scale, so if that works better for you, get a small postal scale and measure the materials out in grams.

For one buckle blank, I measure 1 dram (⅛ fluid ounce) of hardener in one cup and 1 dram of resin in a second cup.

Fig. A: Evenly coat the blank interior with Mod Podge. Fig. B: Gently press the image down and smooth it out. Fig. C: Pour the hardener into the resin, scraping the sides with a craft stick. Fig. D: Pour the resin into a clean cup and stir for another minute. Fig. E: Gently pour the resin in, covering the whole image. Fig. F: Blow gently across the surface using a straw. Fig. G: Pair your new buckle with an awesome belt and show it off.

3b. Pour the hardener into the resin. Scrape the sides with a craft stick to get as much of it as possible into the resin cup (Figure C).

Stir for 2 minutes. Be gentle, to avoid creating too many air bubbles. Scrape the sides and bottom to get a good mix. The resin will go from cloudy to clear during the mixing.

3c. Pour the mixed resin into a clean medicine cup and use a clean stick to stir it for 1 minute more. Again, scrape the sides and bottom (Figure D). If the resin isn't mixed well it ends up with a sticky surface because it doesn't cure properly.

4. Pour the resin.

4a. Prop up one end of the buckle blank with your scrap material to level it, so you'll get an even surface on your buckle after the resin cures.

4b. Pour the resin gently into the blank to avoid spilling it over the sides. Make sure the resin covers the entire image (Figure E).

4c. To release any bubbles, use a drinking straw to blow gently across the surface of the resin. Some people use a hair dryer, a heat gun, or a small torch. I find that the heat gun causes the resin to splash over the sides, and the torch can scorch the image or the resin, so I prefer the straw method (Figure F).

Cover with a small bowl or other container to prevent dust or pet hair from marring the surface.

5. Let the resin cure.

Resin will harden after 24 hours, but most brands need 36 to 48 hours for a full cure. Follow the instructions included with your resin.

After it's cured, you can remove any small drops of resin that may have fallen on the metal buckle blank with a sharp craft knife. Gently use the edge of the blade to get under the resin, and it will pop right off. Be careful not to scratch the buckle, and don't let the excess resin you just removed fall onto the surface of the buckle. Sometimes the resin will stick to itself if it isn't fully cured yet, and you'll mar the surface of the buckle trying to remove it.

That's it! Pair your brilliant new buckle with the belt of your choice (Figure G).

Jenifer Bryan is a graphic designer and photographer who lives in Austin, Texas. Check out her website at lucybluestudio.com.

“Without our ShopBot and the great community of other ShopBotters, we would have never made it this far. Thanks to ShopBot and my fellow ShopBotters for helping us to live our dream of creating new and exciting designs.”
Angus Hines, Hines Design Labs
www.AngusHines.com

Angus Hines’ life as a Maker began at the age of two when he took his first toy apart to see what made it work. From that point on, if it had screws or could be taken apart and dissected, nothing was safe. He was bound and determined to see what made things work and find ways to make them work better.

After he retired from his career as a project manager and spent some time cruising the Chesapeake Bay, Angus began to get bored and restless. He turned to his first love of creating new things and purchased a laser engraver. Angus started Classic Marine Co. and began making instrument panels, indestructible LEDs and other marine Items, but, as business grew, he decided he needed a larger, more versatile platform. Angus purchased a ShopBot and expanded into larger design projects like furniture, small buildings and larger marine items. Not content to make things that already exist, he started another company, Hines Design Labs, and has now ventured into prototyping, design assistance and helping people take their ideas from a napkin sketch to a finished product. Angus’ love of making has taken his company from a small marine manufacturing facility to a full-blown design prototype shop, and his ShopBot helped make it all possible.

What will you make today?

888-680-4466
www.shopbottools.com

BUILD NOTES

How PES makes his stop-motion movies.

Boiling Spaghetti Without Water

BY PES

MY ANIMATED SHORT FILM ENTITLED *Western Spaghetti* features me cooking spaghetti with all sorts of familiar objects substituted for real ingredients. For example, rubber bands double as spaghetti, Post-it Notes as butter, and tinfoil as olive oil (Figures B, C, and D).

I brought all the objects to life using traditional stop-motion animation, and created all the effects entirely in-camera by manipulating the objects from frame to frame (see the setup in Figure A). There are no computer-generated effects in the film.

Stop-motion animation requires that one control objects and move them in small increments from frame to frame, photographing them in each position. You can do this with puppets, objects, or people — anything that can be put in front of a camera can be moved incrementally and photographed in this manner.

The resulting sequence of images (approximately 1,500 in *Western Spaghetti*) creates the illusion of motion when played back at normal speed. You can bring inanimate objects to life at will, as long as you are willing to put in the time.

Sometimes animating objects is straightforward. You find the objects, you arrange them in front of the camera, you photograph them. Then you move them (or replace them) and repeat the process over and over. For instance, to make a sugar cube (represented in *Western Spaghetti* by a single die) appear to dissolve in tomato sauce (undulating red velvet), I replaced the die in each frame with smaller and smaller versions of the die, all the way down to an 8mm doll-sized die. When played at normal speed, the cube appears to dissolve into the red velvet.

Sometimes, though, you come up against a real challenge when animating objects — like water, for instance. Real water cannot be manipulated frame by frame because it cannot be controlled like clay, a more traditional material choice for stop-motion.

This makes water one of the most stop-motion "unfriendly" substances. Unfortunately for me, water was the one ingredient I needed most: you can't make spaghetti without water.

Water appears in seven shots in *Western Spaghetti* — 20% of the film — and a different creative solution was required each time. Here are four different methods I used to portray water:

How I Created the "Water"

1. I began with a shot of my hands placing a pot full of water on the stovetop. To create this "water" I used a single sheet of acetate, the kind you'd put in an overhead projector. It was cut in the shape of an oval, slightly larger than the diameter of the pot, so that it would suspend itself naturally in the pot. It could then be manipulated frame by frame to behave like real water swishing around a pot. A small light was reflected off the acetate to further sell the shiny water effect to the viewer (Figure E, page 145).

2. As every Italian cook knows, sea salt (represented in the film by googly eyes, chosen because of the pun "see salt") must be added to the water before boiling. The challenge was how to get the googly eyes to sink through the acetate water like real salt does when you throw it into the pot.

In addition, I didn't want the googly eyes to sink to the bottom of the pot all at once. I wanted them to have a slight delay when falling, staggered in three groups to feel more natural.

The solution: three small braces were affixed to the inside of the pot, out of frame. Each brace had ten notched grooves, so that ten sheets of acetate could be suspended simultaneously inside the pot (Figure F). The idea was to move the sheets of acetate — each with googly eyes glued to them — down one layer in each shot, giving the impression

Photography by PES

How PES makes his stop-motion movies.

that the googly eyes were sinking toward the bottom of the pot.

To enhance the feeling of depth to the water, the large googly eyes were replaced with incrementally smaller googly eyes as they progressed down the structure, for a total of four different sizes of googly eyes (Figure G).

3. Next up: a pot of boiling water. In order to create this effect I manipulated different sizes of bubble wrap in stop-motion.

The boiling water shot begins with a lidded pot boiling over with water. To achieve the effect I cut small pieces of bubble wrap and moved them incrementally down the side of the pot and in the crevice between the pot and lid. This was detailed work, at one point calling for the use of a single bubble of bubble wrap squeezed between the pot and the lid (Figure H). One of the absurdities of making a film like this is discovering that there can be a use for such a thing as a single bubble of bubble wrap.

When my hand lifts the lid off the pot, I reveal a pot full of boiling water. It is made of big, clear, juicy bubble wrap cut in a disc to fit perfectly in the pot (Figure I). The disc's position was alternated randomly so that it would look like boiling water rather than a piece of bubble wrap being turned like a disc.

4. In order to achieve the final three-second shot of the wooden spoon stirring the cooked spaghetti, I used a combination of the previous techniques. My first goal was to make the spaghetti appear to float in the water; my second goal was to make the spaghetti move clockwise when stirred (as in real life, responding to the spoon pushing it); and my last goal was to keep the water boiling on top of it all.

First, I suspended a few layers of thick acetate in the pot, with rubber bands (my spaghetti) resting on each layer (Figure J). This gave dimension to the spaghetti and made it appear as if it were floating in the pot, at different levels.

A hole was then cut in the top acetate layer to allow the wooden spoon to sink in and appear submerged in the "water." Then, a circular sheet of bubble wrap was laid on top of everything, hiding both the hole in the acetate and the plastic tabs that were holding up the acetate layers on the side of the pot (Figure K).

The final trick was to animate all these elements — including my hand — together. The layers of acetate with the spaghetti resting on them had to be twisted clockwise in small increments while, on top, the bubble wrap was moved randomly to make it appear that the water was boiling.

Conclusion: The Allure of Hands-On Puzzle-Solving

There is a directness to working with objects in front of a camera rather than inside the theoretical space of the computer that stimulates both the thinker and the tinkerer in me. The allure of making a film like *Western Spaghetti* is that it requires hands-on puzzle-solving bound by real-world limitations.

With stop-motion you aren't playing in a realm of infinite possibility as is often the case inside the virtual environment of the computer. You are bound by the laws of physics and gravity and materials, and must find creative ways to deal with them. I find that these limitations often lead to harder thinking and more creative solutions — solutions that connect with audiences on a deeper psychic level because they are rooted in reality.

Making a film like *Western Spaghetti* is very much like being a sleight-of-hand magician. The results can feel magical, but there's no actual magic. If you look closely (you can do this by scrubbing through frame by frame on the QuickTime movie) you can probably figure out exactly how every effect was created and what material was used. My job is to exploit the cracks and weaknesses in viewers' perceptions so they don't fixate on the process and can instead just sit back and enjoy the trick.

Watch *Western Spaghetti*: eatpes.com

PES is an artist who has earned global recognition for his innovative short films and unique approach to stop-motion animation. Often working with familiar foods, household items, and found objects, PES has crafted some of the most memorable short films of recent years, including *Roof Sex*, *KaBoom!*, *Game Over*, and *Western Spaghetti*. In addition to his short films, he has become one of the most commercially successful independent artists working today.

BUBBLING WATER: Make Labs re-created PES' boiling water illusion frame by frame to experience how it's done, from building the braces to suspending the acetate (F) to adding the "see salt" (G), "bubbling" over (H), cooking the "noodles" (J), and seamlessly stirring them (K).

Photography by Ed Troxell

By Lee D. Zlotoff

Snowbound!

The Scenario: You're an avid and experienced snowmobiler off to meet up with a friend at a remote cabin some 60 miles back in a rocky and forested wilderness. You know the terrain can be rough in spots and there's a storm on its way, so you elect to use your older but reliable snowmobile rather than the newer one you bought just before this winter season.

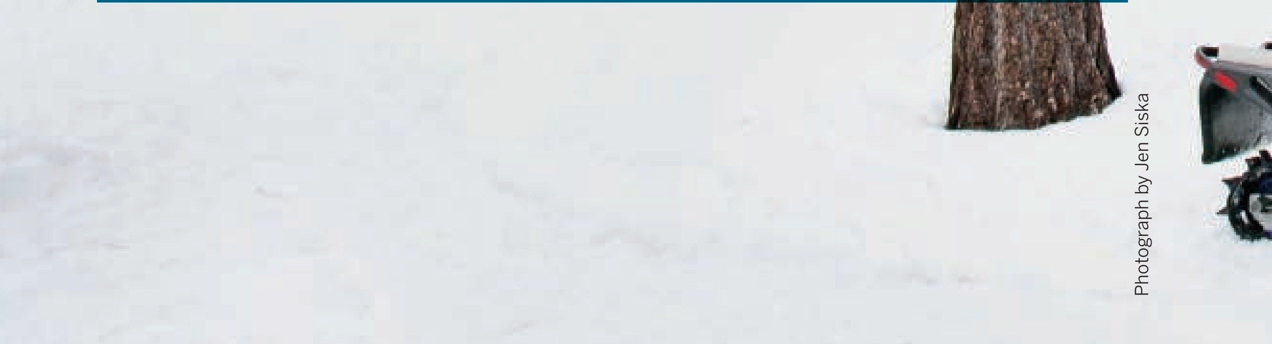
Even though you get started somewhat later than you planned, and the storm seems to be approaching faster than expected, you're still making good progress. You're nearly halfway there when you crest a rise and notice — a split second too late — a sapling jutting up in the trail. Before you can react, one of the front ski tips catches on the sapling and sends you flying off into a snowdrift while your snowmobile crashes into a tree!

The good news is that you emerge unhurt. The bad news is your vehicle is sufficiently damaged that, even though the engine will still start and the gas tank's intact, it's no longer functional for transportation. What's more, in your haste to get on the road you neglected to move the emergency survival kit from your new snowmobile to this one — and your cellphone has never found a signal this far out. No doubt, when you fail to arrive as expected, your friend will come looking for you. But with this wicked snowstorm already starting to pound the area, that might not happen for another 48 hours at best. So, like it or not, you're in for an adventure. And it's up to you to decide what form that will take ...

What You've Got: In addition to the winter clothing you're wearing, you've got two protein bars, a bottle of water, the snowmobile's cover, a basic repair kit consisting of some wrenches, pliers, and screwdrivers, the Swiss Army knife or Leatherman tool you always carry, and the bottle of single malt scotch you were planning to share with your friend at the cabin. What you don't have are any matches, lighters, or time — because the wind is howling, the snow is flying, and the visibility is dropping fast. Are we having fun yet?

Send a detailed description of your MakeShift solution with sketches and/or photos to makeshift@makezine.com by Aug. 27, 2010. If duplicate solutions are submitted, the winner will be determined by the quality of the explanation and presentation. The most plausible and most creative solutions will each win a MAKE T-shirt and a *MAKE Pocket Ref*. Think positive and include your shirt size and contact information with your solution. Good luck! For readers' solutions to previous MakeShift challenges, visit makezine.com/makeshift.

Lee David Zlotoff is a writer/producer/director among whose numerous credits is creator of *MacGyver*. He is also president of Custom Image Concepts (customimageconcepts.com).



Photograph by Jen Siska


CUT iT OUT. I AM THE PUPPET MASTER!
GRRR!
HOW
TRACE SHAPES TO THICKER PAPER.
USE PAPER FASTENERS TO CONNECT!
USE CHOP-STICKS AS CONTROL RODS.
TAPE IT UP!
DRAGOTTA '10


TOONS
NOW SET THE STAGE!
A
B
B
CUT OUT WINDOW ON BOTTOM OF CARDBOARD BOX.
TAPE LARGE SHEET OF PAPER TO INSIDE OF WINDOW TO CREATE SCREEN.
LIGHT
BRAVO
HOWTOONS.com

Espresso on the go, citizen scientists on the web, tinfoil to the rescue, and a glimpse at the new Makers Market.

TOOLBOX

Killer Krawler

$699 chassis kit, $1,200 ready to run rc4wd.com

I have several years of experience in R/C vehicles, and in my opinion, the coolest innovation in the hobby are the crawlers from RC4WD. As the name implies, these are incredible crawling machines that are super fun to build and to run. Like a good video game, they're easy to pick up, but hard to master. Crawlers are built to climb over serious terrain, and some are built as scale trucks that look as realistic as possible (while still being monster crawlers). There's no shortage of stuff to climb, from rocks and firewood in your backyard to your living room couch.

RC4WD's Killer Krawler is the biggest such model in the world. At 1⁄5 scale, it has a fully CNC-machined aluminum chassis, and an articulation angle of 90°.

It has nearly 6" of center ground clearance, and over a 22" wheelbase. As with all crawlers, this one is four-wheel drive, with locked differentials. It has two motors, one on each axle, aka MOA (motor on axle). The gears, along with everything else on this beast, are all metal, so it'll withstand anything you can throw at it. The 30:1 gear ratio ensures high torque for precise crawling. Two ESCs (electronic speed controllers), two motors, a radio system, servo, and a battery are required to complete this kit.

The giant scale of the chassis makes it attractive as a potential robotics platform, able to handle extremely rough terrain, and big enough to carry a truckload of sensors and hardware. RC4WD has hundreds of options and parts to choose from — wheels, tires, chassis, shocks, axles, transmissions, and electronics — to help you easily customize a truck of your choice. *—I-Wei Huang*

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.

Bucket Boss Rear Guard Tool Sheath

$13 bucketboss.com

This is a great tool for wiring data centers or other projects. I run a project where we test high-speed network junk, which keeps me always racking and wiring new gear. Well, by the tenth time I had one hand holding up a router and the other in my pocket looking for a screwdriver, I knew I needed something else. Clearly a full-fledged tool belt isn't needed in a data center, but this little organizer will clip over your belt and make your work so much easier. But never again can you use the excuse of not cleaning up the wiring mess you left behind because you didn't have any zip ties handy. *—Joe McManus*

Lego Mindstorms NXT 2.0

$280 mindstorms.lego.com

Here's the latest Lego robotics kit: upgrades include their new 3-in-1 color and light sensor with LEDs, new ball shooter, tank treads, and updated software.

The software remains much the same, with its graphical programming and simple interface, but there's now an image editor to convert your own images to fit the LCD display, a sound editor to record or convert sound clips, and a built-in R/C menu.

The interfaces for the new features are simple and intuitive. To convert an image in the image editor, all I had to do was adjust the level of detail to be displayed. The sound editor gave me the option to convert *.mp3* and *.wav* files into the NXT's *.ros* sound format. And the remote control menu was most useful: it has direction and speed control for two motors and an action button that controls one motor independently. This is great for testing the motors on your robot without having to program anything!

I'd like to see more storage memory on the NXT, but overall this is a nice refresh on their previous kit and a good step in the right direction. This is an excellent kit for beginning robot enthusiasts but also makes a great gift for veterans. *—Eric Chu*

Silicone Molding Magic

$11 sugru.com

Sugru is a new silicone material designed for hacking, repair, and modification. Open a packet and mold the Sugru into shape. It bonds to smooth metal, ceramic, plastic, and more. It cures in about a day, creating a semi-flexible part that will stand up to much abuse, including temperatures from –76°F to 356°F. It's even UV-, water-, and oil-resistant.

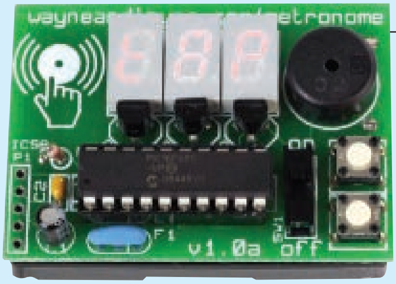
I used it to fix the spout of our teapot. Not many adhesives could survive the heat and steam. Sugru worked perfectly, and lent a stylish air. Sugru's great for many fixes, such as ergonomic grips, handlebar mounts, magnet-embedded tool hangers, laptop feet, and wire insulation. Looking around the house, nearly everything I see could use some improvement with Sugru.

—John Edgar Park

Deluxe Make: Electronics Toolkit

$125 Maker Shed #MKEE2

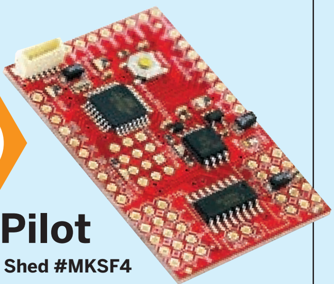
This is for anyone who wants to learn the fundamentals of electronics. We took all the trouble out of finding the right tools for the job, and we even include your first kit, the WeeBlinky, the highly regarded *Make: Electronics* book, and a Maker's Notebook to help you dream.



Tactile Metronome Kit

$25 Maker Shed #MKWL1

Here's an open source tap-controlled metronome, and simple beat-looper, with attitude. You tap the piezo speaker to set the rhythm, and the display shows the beats per minute. You can tap patterns up to 12 beats long, and it will continuously play the rhythm. Makes a great first soldering project!



ArduPilot

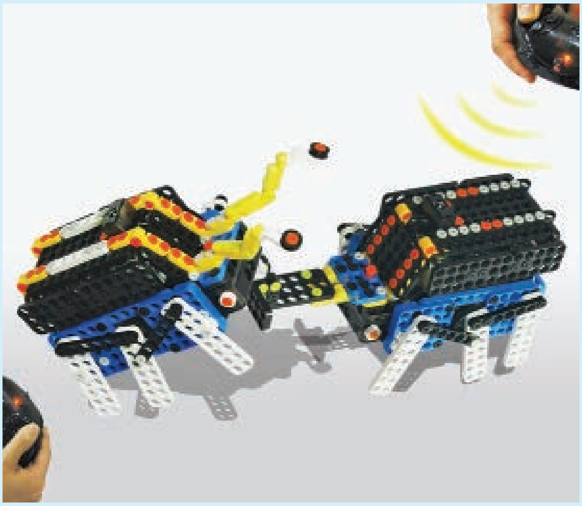
$25 Maker Shed #MKSF4

ArduPilot is a full-featured autopilot based on the Arduino open source hardware platform. It handles both stabilization and navigation, eliminating the need for a separate stabilization system. ArduPilot is the autopilot used to win the 2009 SparkFun Autonomous Vehicle Competition.

Ollo Bug Kit

$100 Maker Shed #MKOL2

The Ollo bug is a reconfigurable robot that can trace lines, detect objects, and be controlled via wireless remote. The modular system makes for quick, imaginative builds. The kit includes detailed and well-illustrated instructions.



Makers MARKET

MAKER-MADE » COMMUNITY-SOURCED

The New Makers Market!

MAKE is thrilled to announce a new, curated marketplace of wonderful science, tech, and artistic creations made and sold directly by some of our favorite makers from around the world. (Read all about its inception on page 29 of this issue.) Here are a few of the things you can find at makersmarket.com, and the makers behind them.

A. Ristau Studio

aristau.makersmarket.com

Aaron Ristau spends his days working on high-tech machines. His nights are spent knee-deep in technology as well — only the technology is often half a century old or more. Creating art from well-made components that would otherwise be thrown away, he lends new life and dignity to yesterday's cutting-edge materials.

Everything Tiny

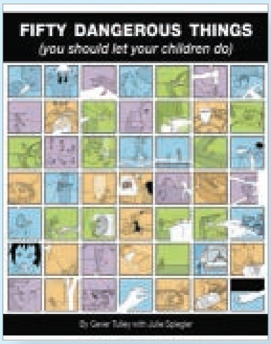
everythingtiny.makersmarket.com

Too much stuff in your workshop? Not to worry, these build-your-own Tinysaurs won't take up much room but will hone your hand-eye coordination and sense of fun. Each kit comes with tweezers, glue, laser-cut parts, and instructions (magnifying glass not included).

Made With Molecules

madewithmolecules.makersmarket.com

Scientist-turned-artist Raven Hanna makes beautiful, smart jewelry inspired by the world on a molecular level. While working on her Ph.D. in biochemistry, she wanted a necklace based on the serotonin molecule, signifying happiness. It didn't exist, so she learned how to make it herself. Stunning visually, her jewelry has a hidden meaning for those in the know.



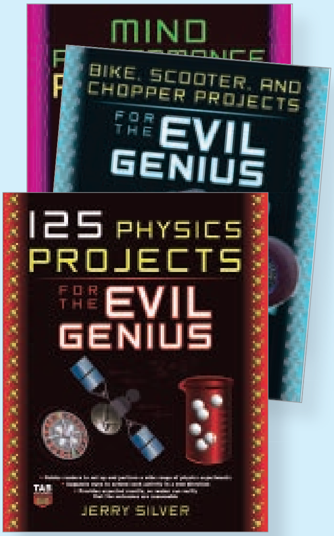
Danger, Danger

Fifty Dangerous Things (You Should Let Your Children Do)
by Gever Tulley with Julie Spiegler
$26 Tinkering Unlimited makershed.com

I thought I was pretty good about letting my kids get into all kinds of questionable activities until I read this book. From building fires to exploding a bottle in the freezer to super-gluing your fingers together, there's a "dangerous" activity to whet the appetite of just about everyone.

My 7-year-old son and I are having a blast (literally) working our way through the activities in the book, and while we've had to postpone a few for when he's older, like melting glass, he's been basking in the thrill of accomplishing many of the inspiring and slightly dangerous tasks.

There's traditional kid stuff in the mix like throwing rocks, climbing trees, and making a slingshot. The authors believe that letting kids interact with their environment is a healthy choice in today's overprotective society. If you pay careful attention, these are not dangerous activities so much as they are great ways to engage with the world. —*Bruce Stewart*

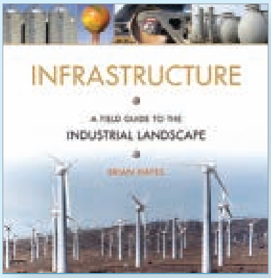


Simply Genius

***Evil Genius* book series**
$25 each McGraw Hill/TAB Electronics

Since 2004, McGraw-Hill has released 25 *Evil Genius* books filled with projects sure to stoke the imaginations of the most jaded makers amongst us. The books run the gamut from robots to bionics to home automation. Although some are targeted at a high school demographic, some will provide a good challenge for adults, and many projects could be done by junior high students under adult supervision.

My favorites are two challenging books written by Thomas Petruzzellis. The sensor book covers projects to measure sound, light, temperature, vibration, magnetic/electrical fields, and radiation. While the radio receiver book is perhaps the most advanced, it will guide you in monitoring the radio spectrum from VLF to UHF as well as lightning storms, the northern lights, or the planet Jupiter. This year promises six new books in the series. —*Chris Singleton*



The Made World

***Infrastructure: A Field Guide to the Industrial Landscape* by Brian Hayes**
$35 W.W. Norton

If you've ever driven through an industrial zone littered with strange structures and uttered with a 5-year-old's curiosity, "What *is* that?" then this is the book for you. Even if you pass by oil fields or power plants with a shudder, Brian Hayes' passion for visually deciphering the stories behind what supports modern civilization is contagious, fun, and important.

Infrastructure isn't just about those places we'd usually avoid; it's a beautifully photographed eye-opener about our "built environment" and the many, many decisions that go into what that is. It's wonderfully subversive — 508 pages of information about mining, power plants, and transportation (among other things), all disguised as a surprisingly enticing coffee table book. —*Meara O'Reilly*

Nike+ Pace Sensor

$59 wristband, $19 sensor only nike.com

I've been running for years and have worked with several devices (often using GPS) to track how far and fast I'm running. I now use the Nike+ system that tracks distance without the need for connection to a satellite.

The Nike+ sensor is a small chip that's placed in your shoe, right under the laces. As you run, it transmits data about your foot strikes to your iPod/iPhone or Nike+ SportBand (shown above). These devices then show your pace and distance traveled while you're running. Unlike other devices that need to be calibrated, the Nike+ is extremely accurate right out of the box, with slightly better results after running a set distance with it.

Getting results on your iPod is a great addition, as you only have to bring one electronic device on your run, and it takes care of your music and pace at the same time. After your run, plug it in and the data is uploaded to the Nike+ running club website, so you can keep to a training regime. I've also enjoyed challenging friends in the club to run certain distances or achieve certain times. *—Jeremy Kerfs*

Acme Klein Bottles

$35 and up kleinbottle.com

I received an Acme Klein Bottle for my birthday and I wholeheartedly recommend that you try receiving one for yours. Manufactured by Cliff Stoll in Oakland, Calif., my Klein bottle is made of clear glass, ensuring high visibility of the entire universe contained inside it. Furthermore, like every bottle should (and so few do), it has a handle, giving you a grip on not only your new favorite bottle but also the inside and outside of the bottle at the same time.

Yes, the Acme Klein bottle is everything I wanted it to be (which is to say, a non-orientable, zero-or-infinite-volume-depending-on-how-you-think-about-it, one-sided container) and more — it has also done wonders as a conversation piece at parties. Which brings me to my one and only disclaimer: avoid allowing partygoers to use your Klein bottle as an actual drinking vessel. Through no fault of the manufacturer but rather by their very nature, Klein bottles are not easy surfaces to wash. *—Natalie Wolchover*

Society for Amateur Scientists

Free sas.org

Many of my MAKE activities center around Earth sciences (the aurora borealis, earthquakes, and weather), and while there are many sources of web-formation that can tell you what's been done in the past and guide you in finding your own path, there's one that's truly special, a treasure trove to inspire your own scientific projects.

The Society for Amateur Scientists was started in 1994, and its 2,000 members are interested in conducting real-world scientific research. (Something the general population may not know is that many significant discoveries in astronomy and other sciences were made by amateur scientists.)

SAS' biweekly webzine *The Citizen Scientist* is the gateway to a vast collection of resources including almost every "Amateur Scientist" column published by *Scientific American*, hundreds of science fair projects, the new LabRats youth science program (labrats.org), and a new online research platform (idoscience.org) that promises to bring together amateur and professional scientists.

—Chris Singleton

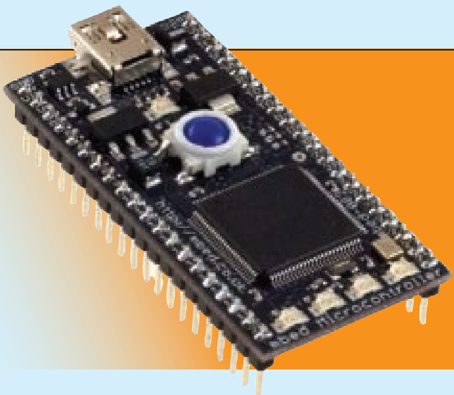
Swivel LED Flashlight

$72 energizerlightingproducts.com

There's something primordial about lumens. Our forefathers literally burned the midnight oil. Today, flashlights make us masters of the dark.

With a form factor and feature set inspired by consumer input, the compact Night Strike Swivel sports a 130° swivel head with a centrally located 100-lumen Cree XRE white LED, as well as red, green, blue, and near-ultraviolet Nichia LEDs. With the exception of the UV, each LED operates in high, medium, or low capacity. Locating a water leak, or reading in the dark without destroying your night vision, has never been easier!

The lightweight, weatherproof magnesium-alloy case provides users with a rugged, soft grip while maintaining the thermal management necessary for optimum LED operations. Run-time tops out at five hours on maximum settings. *—Joseph Pasquini*



mbed Microcontroller

$99 mbed.org

The mbed microcontroller offers a unique rapid prototyping solution. The hardware itself is ARM-based and has many bells and whistles — Ethernet, USB, PWM, analog input/output, serial, SPI, the list goes on — all in a nice, breadboard-friendly package.

And while there are a lot of boards out there with comparable features, this one sets itself apart by having the complete build environment online.

The idea is that you can log into a website from anywhere and work on your project. The tool chain offers an extensive set of library functions, along with several sample projects.

The people running it are pretty supportive of the community (judging by the forum posts). Although it may not appeal to everyone, the "cloud compiling" concept certainly is interesting.

For those who are wary, it sounds like there are also ways to compile offline (GCC?), and they haven't ruled out an offline version of the tool chain. The mbed lists for $99 but is easily found for $60 or $70. *—Timothy Benson*

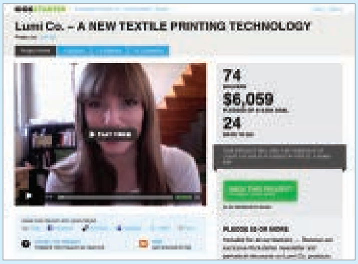
Kickstarter Funding Platform

5% fee kickstarter.com

If you've got a cool idea but not the resources to pull it off, Kickstarter might be just what you need to get things off the ground. It's a website that crowdsources small donations for featured projects.

If you're thinking this sounds like micro-payments all over again, just check out some of the popular projects; Kickstarter publishes the amount raised for each one, and it's inspiring to see so many worthy ideas receiving real money, ranging from book and film concepts, to small business plans, to community improvement ideas.

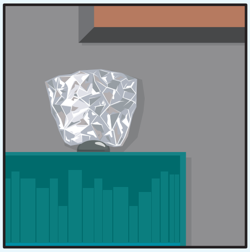
How about a pedal-operated butter churn or a fusion reactor in a bubble-gum machine? Both are currently raking up donations. Submit your next great idea and you might find others willing to help make it a reality. ***—Bruce Stewart***



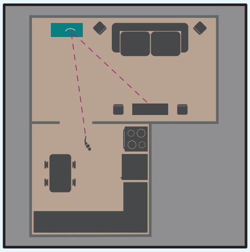
Tricks of the Trade By Tim Lillis

Tech out that tinfoil.

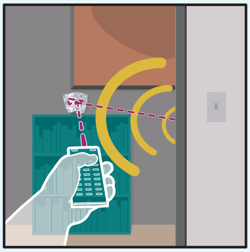
Have a remote controlled device that your infrared remote won't reach? Try this low-cost IR repeater, suggested by Andrew Turley at pillowsopher.com.



Using tinfoil, make a curved plane, like a radar dish. You can use almost anything as a base, though you don't need one. I used an old business card holder.



Don't worry about smoothing out the wrinkles, they'll actually help spread the signal. Experiment with placement for the best signal.



Now you can change that song, channel, movie, or how-to tutorial all from the next room.

Have a trick of the trade? Send it to tricks@makezine.com.

Portable Espresso Machine

$169 mypressi.com

Feel the need to pack some serious espresso gear when you travel far from a café? Me too. The next time you're confined to a hotel, tent, or non-coffee-obsessed relative's guest room, consider bringing a Mypressi Twist. I've tried other portable espresso makers, and they made disappointing quasi-espresso. The Twist is the real deal. With a nitrous oxide cartridge and its specially engineered set of tiny regulator valves, it generates the proper 9 bars of pressure needed to transform fresh grounds and preheated water into a nuanced, crema-topped shot of espresso.

Just like the portafilter on my workhorse, plumbed-in Italian machine at home, I found it important to preheat the Twist with boiling water for a minute or two and then dump that before making the real shot. (Low temperatures make for sour shots.) I adjusted the dose and grind level to dial it in even more to my liking. In the end, I was pulling shots that were thick, bright, and delicious by any standard, and spectacular for a handheld travel espresso machine.

—John Edgar Park

Timothy Benson is an embedded software engineer whose hobbies include homebrewing, motorcycles, and music.

I-Wei Huang is a concept artist and animator in the video game industry and a steam-powered robot builder. crabfu.com

Jeremy Kerfs is an avid runner and robotics enthusiast.

Joe McManus is a network security researcher at Carnegie Mellon University and is off on adventures in the woods the rest of the time.

John Edgar Park is the host of the Maker workshop on *Make:* television.

Joseph Pasquini is an avid amateur radio operator with a career spanning over 15 years in the fields of information security and systems management.

Christopher Singleton, a father of three boys, is a maker, inventor, writer, and product development specialist.

Bruce Stewart is a freelance technology editor and writer, as well as an infrequent contributor to *Wired*'s geekdad.com.

Natalie Wolchover is a 23-year-old ex-physicist who just dropped out of a Ph.D. program at UC Berkeley to start a career in science journalism instead.

Have you used something worth keeping in your toolbox? Let us know at toolbox@makezine.com.

By Donald Simanek

Puzzle of the Crowned Pulleys

Real-world problems in physics sometimes take quite a while to figure out, unlike the contrived problems in textbooks that must be solved by next week.

» One such real-world problem first came to my notice when I was a child growing up on an Iowa farm in the 1940s. At that time few farmers could afford grain-threshing equipment, and the custom was to share a threshing machine that would go from farm to farm.

The farmers brought the shocks of grain from the field to the machine, and then took the threshed grain to storage. The machine blew the straw into a huge pile. Too young to be asked to do any of this heavy work, I watched the whole process with fascination.

The threshing machine seemed huge, and was driven by a flat leather belt powered by a stationary farm tractor. The belt was perhaps a foot wide or more. Of course the thresher and tractor had to be properly aligned, and blocked so they wouldn't move. What puzzled me was how that 20-foot-long belt could run all day and remain on the cylindrical pulleys without wandering off. The belt might not track properly until the tractor was properly positioned, but once that was accomplished, it usually needed no further attention. No one I asked knew the answer. "It just works," they said.

At the university, we physics majors studied mechanics and even some material on machines. But this particular problem was never addressed by textbooks or in class. By then it had settled to the cobwebby recesses of my mind. After a career of teaching physics at the university level, I never saw this problem in any textbook. After retirement, I kept busy with a website, mostly about physics, and people would send me questions by email. One of these asked about flat belt tracking.

Solving the Puzzle

Foolishly thinking I could brainstorm this myself, I first considered friction effects. Then I got smarter and sought out a real farm tractor that had the usual drum cylinder for flat leather belts. I noticed that this cylinder wasn't of uniform diameter, but was of slightly larger diameter at its center. Other belt-driven machinery revealed the same thing. Aha!

Could this somehow be causing the belt to ride onto this elevated center section and stay there? But why would the belt prefer a larger diameter, and greater tension? It seemed counterintuitive, but one thing I've learned in my years in physics is that one's naive intuition is usually wrong.

Back to the laboratory, and more experiments. At first I suspected friction had something to do with it. But the friction acts in the wrong direction, opposite the observed centering movement of the belt. Of course friction is important to the operation of the machine, because without it the belt wouldn't turn. But perhaps something else was going on.

Along the way I remembered the old adage, "Sometimes an hour in the library can save you weeks in the laboratory." I searched engineering mechanics books, a genre of literature I had seldom consulted before. And I came up blank. These books didn't mention such mundane matters as pulley centering. The internet wasn't much help either, except to describe this kind of pulley as a "crowned pulley," and to give specifications for the elevation of the center as a function of the pulley radius.

It's always easier to find information about something once you know its name. At a used-book sale I gravitated toward the engineering section, and there I found an older textbook, *Elements of Mechanism* by Peter Schwamb, Alynne L. Merrill, and Walter H. James, third edition (New York: John Wiley & Sons, 1921), and was astounded to see an excellent discussion that tackled the question of crowned pulleys head-on, giving a very good explanation that even a physicist could appreciate and understand. Today you can find it on Google Books.

(I love older textbooks, for they had real informa-

One thing I've learned in my years in physics is that one's naive intuition is usually wrong.

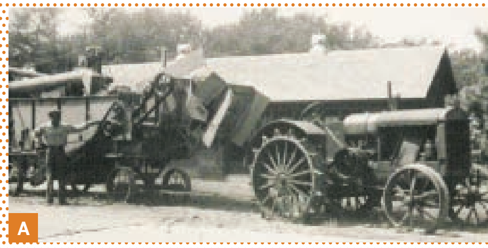
tion and good explanations. This is the sort of book that libraries too frequently discard because it doesn't get checked out, because it's a textbook, and because it's old. Newer textbooks, in spite of their obscene size, have so many glitzy color pictures that there isn't enough space for the necessary words.)

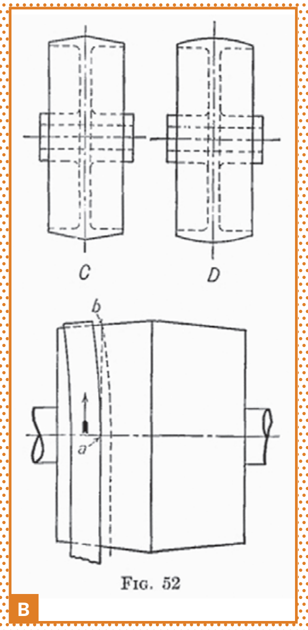
Here's what this textbook said:

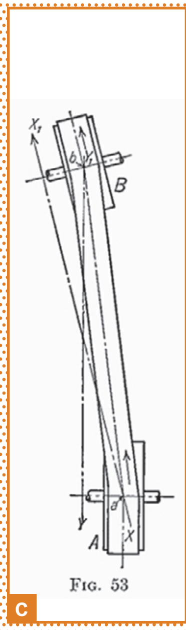
> *If a belt is led upon a revolving conical pulley, it will tend to lie flat upon the conical surface, and, on account of its lateral stiffness, will assume the position shown in Fig. 52 [right]. If the belt travels in the direction of the arrow, the point a will, on account of the pull on the belt, be carried to* b*, a point nearer the base of the cone than that previously occupied by the edge of the belt; the belt would then occupy the position shown by the dotted lines. Now if a pulley is made up of two equal cones placed base to base, the belt will tend to climb both, and would thus run with its center line on the ridge formed by the union of the two cones. ... The amount of crowning varies from about $\frac{1}{16}$ inch on a pulley 6 inches wide to about ¼ inch on a pulley 30 inches wide.*

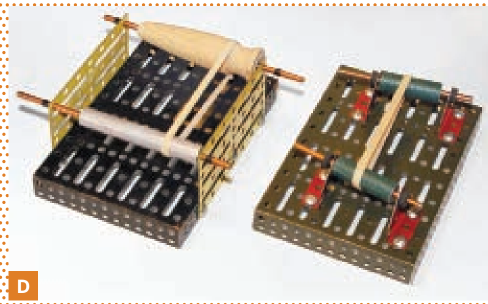
The belt in contact with the truncated cone lies on the pulley relatively flat and undistorted in shape. But along the dotted line at point *a*, the belt moving upward makes first contact with the pulley. Just below *a*, the belt has a slight sidewise bend. But the important thing is that as the belt moves from *a* to *b* without slipping, it moves along the dotted line to a point farther up the incline of the cone, and this process continues until the belt rides onto the apex. It's geometry!

Now let's look at the case of a flat belt running over two cylindrical pulleys whose axles are misaligned. Will the belt crawl to the right (where the belt tension will be higher) or to the left (where the tension is









RIDING HIGH: Fig. A: Threshing machine, 1940s. Note the drum pulley on the tractor; It's the smaller cylinder between the front and rear wheels. Fig. B: Two types of crowned pulleys and an analysis of the belt passing over a tapered pulley. Why does the belt ride onto the elevated center instead of slipping off? Fig. C: The belt passing over misaligned pulleys. Fig. D: My two pulley models. At left, the wooden file handle acts as the crowned pulley. On the misaligned pulleys at right, the belt migrates to where the pulleys are closest together.

Photography by Donald Simanek; diagrams from *Elements of Mechanism* (1921) lower)? After thinking it through, try it and you may realize that a different reason must be sought than the one we found above, since your intuition may have misled you again.

Quoting *Elements of Mechanism*:

> *When pulleys are located on shafts which are slightly out of parallel, the belt will generally work toward the edges of the pulleys which are nearer together. The reason for this may be seen from Fig. 53 [previous page]. The pitch line of the belt leaves pulley* A *at point* a. *In order to contain this point, the center plane of pulley* B *would have to coincide with* XX_1. *Similarly, the belt is delivered from* b *on the under-side of pulley* B, *into the plane* Y_1Y. *The result of this action is that the belt works toward the left and tends to leave the pulleys.*

This passage is a little murky at first reading. The essential difference between the two cases can be seen in the diagrams. As seen on the previous page, in our Figure B (their Fig. 52), the belt makes contact with the pulley at line *a*. Note that the upper edge of the pulley (line *b*) makes an angle with line *a*. Also, note that line *a* is perpendicular to the incoming portion of the belt.

In our Figure C (their Fig. 53), the belt makes contact with the pulley at line *a*. Note that the upper edge of the cylindrical pulley (line *b*) is parallel to line *a*. Also note that line *a* is not perpendicular to the incoming portion of the belt.

This is the important difference between the two cases. In Figure B, each new piece of belt coming onto the pulley is carried, without slipping, to a point higher (to the right) on the slope. In Figure C, each new piece of belt coming onto the pulley is "laid onto" the pulley at a point slightly lower (to the left) on the slope, and is carried around without slipping.

An example of a crowned pulley can be found in the drive wheel of a band saw. This demonstrates that the principle also works with steel belts, which are much more rigid laterally than leather or rubberized fabric belts.

What I like about this puzzle is that the behavior of the crowned pulley is counterintuitive; that most of the initial hypotheses you make will turn out to be wrong; and that some explanations of the crowned pulley seem so "right" — until you apply the same reasoning to the parallel shaft problem, and then it's back to the drawing board.

I like puzzles that have several levels of apparent paradox and counterintuitive features. They teach us to use, but not to trust, our intuition, which is a good lesson.

I like puzzles that have several levels of apparent paradox and counterintuitive features. They teach us to use, but not to trust, our intuition, which is a good lesson. Intuition can sometimes be a part of the problem-solving process, but at some point, it must give way to "sweating the details" and being ruthlessly critical of "plausible-sounding" answers.

Test It Yourself

Even after reading the explanation, you may still be skeptical that it really works this way. Good! I urge basement tinkerers to try it with real belts and pulleys. I used Erector construction set parts, some wood turnings, metal cylinders, and rubber bands, only because they were handy.

Figure D, on the previous page, shows my two models. The model on the left has a wooden file handle as a crowned pulley. This serves to illustrate how the rubber band will migrate along the wooden pulley from the narrowest part at the left, to its largest diameter. The file handle has both convex and concave profiles. Placed in the concave part, the rubber band will quickly rise up the slope and will stabilize at a larger radius, even if that is the very narrow portion near the right end.

The second model (on the right) has two misaligned pulleys. In this model, it's better to use wooden dowels, or to cover the metal cylinder surfaces with something like cloth tape, to prevent slipping. When turning, the belt migrates to the end where the pulleys are closest together.

Donald Simanek is an emeritus professor of physics at Lock Haven University of Pennsylvania. He writes about science, pseudoscience, and humor at www.lhup.edu/~dsimanek.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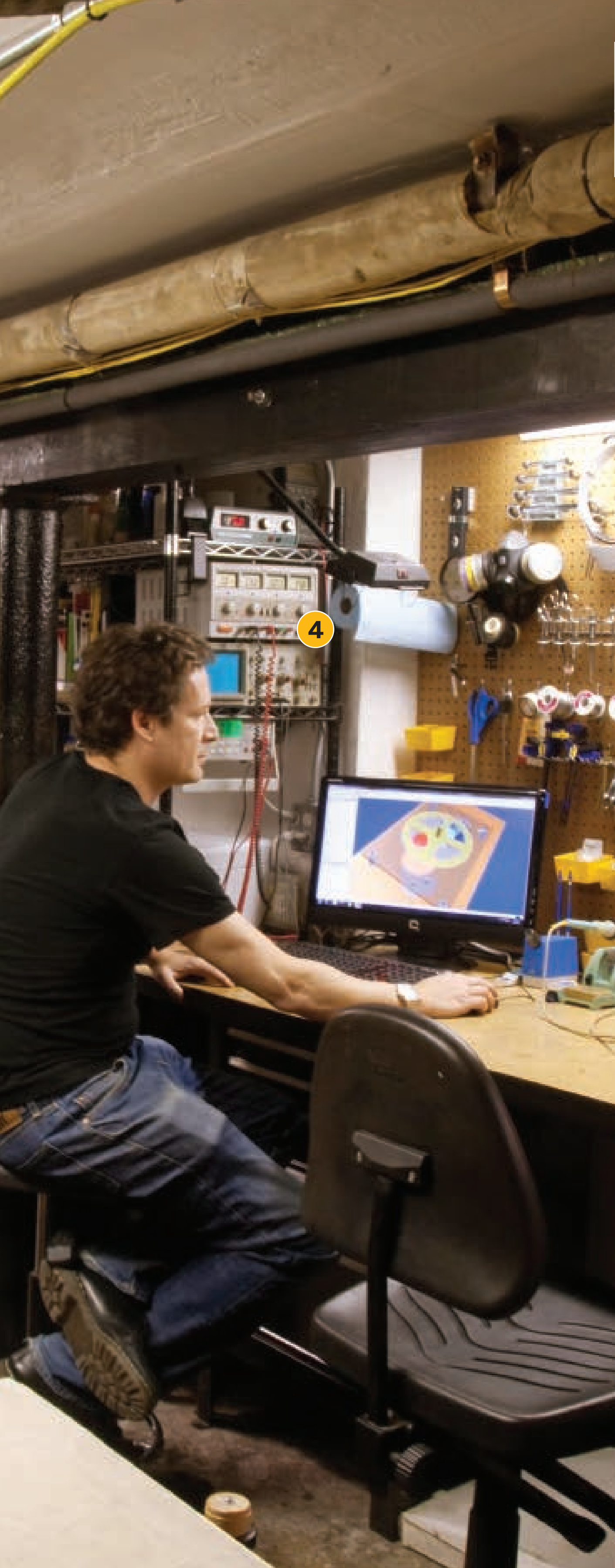

Workshop

» Manhattan's Best Basement Shop

Executive Suite

People who build stuff need work spaces. In the country or in the suburbs, workshops in pole barns and second garages are common. But what if you live on New York City's ritzy Upper West Side, where 1,200 people reside on every block, and garages are as rare as opossums?

Michael Dubno is a Wall Street executive, passionate maker, and owner of arguably Manhattan's best basement workshop, which he's stuffed with a CNC mill, laser cutter, and more tools than Aisle 12 at Home Depot.

Among his many projects is a coffee-table-sized device that draws intricate pictures on a bed of sand using a magnetically coupled, computer-controlled ball. He's also machined a scale model of a key timekeeping component of the Long Now Foundation's 10,000 Year Clock.

Currently, Dubno is re-creating the Antikythera mechanism (see *MAKE Volume 17, "The Kosmos in a Box"*). The incredibly complex, 2,000-year-old orrery, made from bronze gears, shafts, and pins, is thought to be the world's oldest computing device.

—William Gurstelle

1. Medium-duty electric chain hoist. 2. Smithy model 1324 3-in-1 lathe/mill/drill with digital readout and homemade CNC controller. 3. Epilog CO_2 laser engraving and cutting system. 4. Digital oscilloscope, frequency generator, and electronic test box. 5. Project: Prototype of Antikythera computing mechanism made from plexiglass and aluminum. 6. Project: Model of central cam on the Long Now clock (longnow.org). 7. Project: External combustion heat engine. 8. DeWalt variable-speed scroll saw with stand. 9. Jet combination belt sander/disc grinder. 10. Jet 12-inch open stand band saw.

» Like what you see? Make sure to check out MAKE's Ultimate Workshop and Tool Guide, a special edition coming to a newsstand near you this fall 2010.

HEIRLOOM TECHNOLOGY

By Tim Anderson

Crooked Knife

You can easily make your own version of the northern nomad's woodworking tool.

» The crooked knife is the northern nomad's woodworking tool. All the northern tribes in North America and Asia have their own version of it. My farm relatives use them to trim their horse's hooves. I think that whatever wave of invaders brought horse culture to Europe must have brought this style of knife with them.

I made this particular knife (Figure A, opposite page) years ago from plans in the book *Wildwood Wisdom* by Ellsworth Jaeger (1945).

Jaeger's Plans

Jaeger's drawings are a bit vague about blade shape (see Plate 88, at right). When you hold the knife as seen in Figure A, the side of the tip is bent toward you. The side of the blade facing away from you is left flat; don't grind on that side at all. All the grinding is done on the side of the blade toward you.

He describes how an Indian craftsman "tempers the blade, hard at first, and draws the temper by heating to a yellow color." By "yellow color" he means a yellow oxide layer, not a yellow heat glow.

In 1945 everyone would have known exactly what he meant from watching blacksmiths at work. Today these words need further explanation. For more details read *The Making of Tools* (1973) or any other blacksmithing book from your local library. Here's the full text of Jaeger's description:

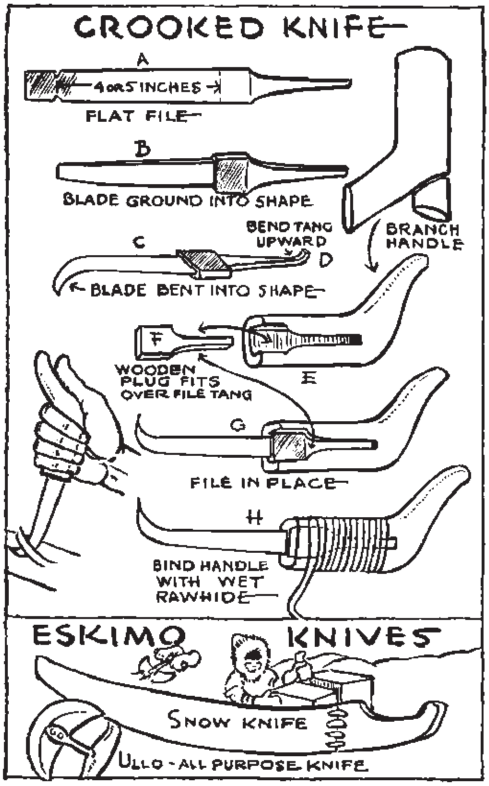

PLATE 88

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Illustration from *Wildwood Wisdom* by Ellsworth Jaeger (1945)

Crooked Knife: A common wilderness knife found among the northern Indians and Eskimos is their famous "crooked knife," so called because of its shape. With this knife the Woods Indian can make many things he needs, from noggins and ax handles to canoes and canoe paddles. It is really an aboriginal draw knife, for in using it, the Indian draws it toward him.

The Indians trade for files at the Hudson's Bay posts and make these into knives (Plate 88). A flat file is used, cut down to 4 or 5 inches (A). The small end of the file, or "tang," is left on; for this fits into the wooden handle. The file itself is then ground down to a cutting edge (B). The Indian then heats it to a cherry red and bends the front of the blade as (C) shows. The tang is bent in the opposite direction (D).

He then tempers the blade, hard at first, and draws the temper by heating to a yellow color. The handle is made from a bent root or branch. The tang of the file is placed against the handle and its outline traced upon it. This part is cut out deeply (E) so that the file and a wooden plug (F) will rest flush with the handle. When the wooden handle has been smoothed and shaped to the Indian's satisfaction, he places the file in its notch (G), and the plug is hammered home. The handle is then bound with sinew which shrinks as it dries and binds the blade as with an iron band (H).


A


B


C


D

My Old Crooked Knife

I made my knife just that way, except I used an industrial hacksaw blade instead of a file for stock. Some saw blades are made with hard teeth and a soft blade, but the back of this one is hard enough to hold an edge without any hardening/tempering.

I carved the handle from a chunk of an elm tree in our yard that was dying of Dutch elm disease. I wrapped the handle with a strip of elm bark to hold the side plug in place. The wood of the handle shrank and gripped the tang of the blade as it dried, so the whole thing is very secure (Figure B).

The handle is a bit small, since my hand has grown a lot since I made it. It fit perfectly at the time, but now that I've seen and used many crooked knives, I would make the handle much smaller where it meets the blade.

Elm is really nice wood. Like oak it has transverse rays in the grain that prevent it from splitting. It's too bad all those trees died.

Mod a Hoof Knife

The quickest way to make a crooked knife is to modify a hoof knife from a farm supply store. Some pet shops carry them with the horse equipment. The hoof knife tip is for cleaning a horse's hoof. The tip fits into the contours around the "frog," which is the living part of the underside of the hoof. For carving wood you don't need that much of a bent tip.

Here's how I modded a hoof knife into a crooked knife in about half an hour. I started with a sharpening stone in a leather sheath with Sami glyphs on it that a Finnish friend gave to me. It works perfectly as a sheath for the crooked knife with the blade next to the stone (Figure C).

I bought an unmodified hoof knife for $5.35 from a feed store. It was made in Pakistan and has a stainless steel blade. Non-stainless is usually better. A blade that can rust is usually much better steel.

1. Cut off the end of the handle so it feels better on your thumb. Be aware that hoof knives come in right-handed and left-handed versions. Get the correct kind for you.

2. Cut off the curled-over tip of the blade.

3. Straighten the blade to suit yourself. Figure D shows a finished knife (bottom) next to a stock one (top) for comparison.

4. Suit the bend to the work you're doing. The knives used for finishing cedar canoe planks are mostly straight with a slight bend in the tip. The Salmon people use a crooked knife with a very long handle and a very small bent blade. They use it for carving details on totem poles, among other things.

Tim Anderson (mit.edu/robot) is the co-founder of Z Corp. See a hundred more of his projects at instructables.com.

Photography by Tim Anderson

DANGER! Put Strange Stuff in the Microwave

By Gever Tulley with Julie Spiegler

Experiment with electromagnetic radiation in the kitchen.

HOW-TO

Metal Foil

A CD is just a thin sheet of aluminum foil sealed between circular sheets of hard plastic. Microwaves are absorbed by metal (that's why you are never supposed to put cutlery in the microwave) and when the metal is thin enough, surprising things can happen.

1. Place an unwanted CD on a paper towel in the microwave.
2. Run at full power for 3 seconds.

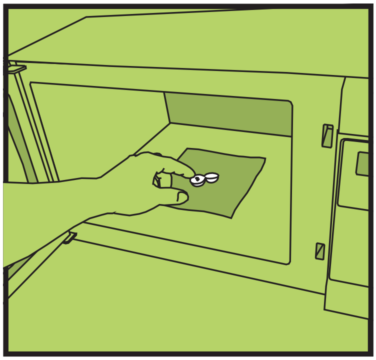
The Grape Antenna

All radio wavelengths can be measured as the distance between peaks in the waveform. As it turns out, a common grape is about one-quarter of the wavelength of the energy produced in a microwave oven — a magical relationship for highly efficient antennas.

1. Cut a grape almost in half, leaving the skin as a hinge between the two halves.
2. Place the grape, open faces up, on a microwave-safe plate.
3. Run at full power for 10 seconds.

Marshmallow Fluff

Besides being sweet, marshmallows have a few properties that make them perfectly suited for microwave experiments: they are fluffy, stretchy, and moist. The water content helps them absorb



REQUIRES
Microwave oven
Grapes (or grape tomatoes)
Unwanted CD
Marshmallows

Duration: 10 seconds **Difficulty: Easy**

microwaves, the trapped air makes them heat quickly, and the taffy-like consistency means that they can expand stupendously.

1. Place a marshmallow on a microwave-safe plate in the oven.
2. Run at full power for 10 seconds.

A microwave oven is really a high-energy physics laboratory that we use every day.

What will you try next?

WARNING

Before we start putting things in the microwave, there are a few rules we must follow in order to minimize the danger to ourselves and the microwave.

» ***10-Second Limit*** *— Never power any experiment for more than 10 seconds at a time.*

» ***Cancel and Contain*** *— If the experiment should happen to catch fire, immediately hit the Cancel or Stop button, and keep the door closed until the fire goes out.*

» ***Expect It to Be Hot*** *— Small objects that absorb microwave energy have a tendency to heat up, sometimes spectacularly. Use an oven mitt or tongs when removing experiments from the microwave.*

SUPPLEMENTARY DATA

Microwave ovens occasionally have dead spots. If any of your experiments fail to produce interesting results, try repeating them in different locations within the oven.

Excerpted from *Fifty Dangerous Things (You Should Let Your Children Do)* by Gever Tulley with Julie Spiegler (fiftydangerousthings.com). Gever is the founder of Tinkering School (tinkeringschool.com), a camp where kids get to use power tools and be trusted.

Illustrations by Gever Tulley

REMAKING HISTORY
By William Gurstelle

The Cave Dwellers of Lascaux and the Oil Lamp

» In Africa, Europe, and China, field scientists have uncovered the fossilized remains of campfire-charred bones so old that they likely predate *Homo sapiens*. The archeological evidence suggests that our humanoid ancestors began taming fire perhaps as long as 1 million years ago.

While these creatures most likely lacked the wherewithal to kindle fire, they did, it seems, have the mental capacity to capture naturally occurring fire, tend it, and preserve it for long periods. For ancient hominids, campfires were important not only for warmth and cooking, but also for light.

About 15,000 to 30,000 years ago, in the Late Stone Age (or Upper Paleolithic), humans painted elaborate images deep within several caves in western Europe, the best-known being those of Lascaux in southwestern France. Narrow and deep, the caves are impenetrable to daylight, making it impossible for the artists to have painted without some sustained source of artificial light.

Experts postulate that these primitive Rembrandts placed a few lumps of animal fat on a stone with a small manmade depression, then lit the fat with a burning faggot from the always-tended campfire not far away. The evidence indicates that in order to produce the hundreds of artworks now considered some of the world's oldest, the painters must have manufactured some of the world's first lamps as well.

As human culture progressed, so did lamp construction. Lamps were made from shells, bone, stone, and chalk, and were fueled by whatever naturally burning, organic substance was locally available. In the far north, it was whale blubber. In parts of the Middle East, lamps were fueled by petroleum products such as liquid asphalt and naphtha, collected from seeps in the ground.

Today the ancient lamps most frequently depicted are those formed from fired clay that burned olive oil. African and Levantine lamps had open tops and were often hung on chains from the ceiling.

What your iPhone is to you, the oil lamp may well have been to the cave dweller.

Later, great numbers of Roman lamps were manufactured using molds instead of hand-forming techniques. They're among the earliest examples of mass-produced housewares. Roman lamps had covers and sometimes multiple spouts and wicks that provided considerable light. It was in the orange-red glow of burning oil lamps that people like Aristophanes wrote, Socrates philosophized, and Archimedes invented.

Designing and fabricating a simple olive oil lamp is easy and fun, and quite possibly, useful. But best of all, when you do it you form a connection with the technology of the past, of the earliest times of human civilization. What your iPhone is to you, the oil lamp may well have been to the cave dweller.

Making an Olive Oil Lamp

Most clay or terra cotta oil lamps work the same way. The fiber skein or string that holds the flame is called the *wick*. Hydrocarbon compounds in the oil are wicked to the flame through the fibers via a phenomenon called *capillary action*. The upward-drawing motion of capillary action results from surface tension, or the attraction of molecules to molecules of similar kind. The oil molecules follow one another up the wick where they burn, or put a bit more scientifically, *oxidize* in a high-temperature, self-sustaining exothermic reaction.

An oil lamp is basically a reservoir for oil with a support to hold the wick upright. In practical terms this becomes a clay pot with a spout for a wick and a separate hole for adding the oil. Making a lamp on a potter's wheel is a simple task, as you need only

CAUTION: Use under adult supervision only. Olive oil is flammable. Avoid spills, and use the lamp with care to avoid fire danger.

Olive oil produces a beautiful, soft orange flame but also considerable soot and smoke. Carefully choose the location where you use the oil lamp to avoid getting soot on walls and ceilings. Oil lamps may set off smoke detectors.

MATERIALS AND TOOLS

- **1lb air-dry clay** Not all air-dry clays become waterproof when cured. For non-waterproof clays, the lamp interior may be coated with varnish or sealant if necessary, to prevent oil leaks.
- **100% cotton fabric**
- **Olive oil**
- **Waterproof varnish or glaze** if using non-waterproof clays
- **Scribes or knives** for inserting the wick into the spout, and for adding decoration (optional)
- **Scissors**

A

B

C

D

E

SEE THE LIGHT: Figs. A–D: The rough shape of a covered oil lamp isn't difficult to make by hand. Fig. E: The various shapes of oil lamps share the same basic features: oil reservoir, spout, and wick.

Photography by Ed Troxell (A–D) and Sam Murphy (E)

throw a simple bowl, then pinch the wet clay to form a spout for the wick. You can even make a decent lamp with just your hands.

1. Shape the lamp.

Olive oil lamps are simple enough to make without a potter's wheel. Almost any shape can be used, as long as it holds oil without leaking or spilling and has a spout and a filling hole. Once your lamp is shaped to your liking, follow directions on the clay package to cure and harden it. Air-dry clay may be used if a kiln isn't available; just paint the interior with varnish to make it waterproof if it's not already.

The simplest shape is a saucer lamp. Raised edges hold the oil and a single depression in the rim forms the wick spout.

Over time, the saucer lamp was superseded by the covered lamp. The covered lamp has several advantages: it's less likely to spill, it usually has molded handles to make it easier and safer to transport, and the cover prevents contaminants from entering the oil reservoir. Figures A–D show the shaping of a covered lamp.

Optional: Improve the finish of your lamp by lightly buffing it with cloth. Lamps can be detailed with scribes or knives, drilled, or sanded if desired. Lamps were commonly decorated with motifs that included mythology, animal and plant life, and repeating abstract designs.

2. Make a wick and fill the lamp.

Cut a piece of cotton cloth ¾" wide by 4" long (the exact length depends on the size of your lamp). Braid or twist the cloth in a tightly spiraled wick. Fill the lamp with olive oil.

3. Insert the wick into the lamp's spout.

Using a scribe or other narrow tool, position the wick so it extends from the bottom of the oil lamp to approximately ½" above the spout. Trim the excess with scissors. Be sure the wick is saturated with oil.

4. Light the wick and enjoy the warm, soft light.

You may need to trim the wick at intervals with the scissors to make it burn faster or slower depending on the amount of light you want it to produce.

William Gurstelle is a contributing editor of MAKE.

Puzzle This By Michael H. Pryor

MAKE's favorite puzzles. **(When you're ready to check your answers, visit makezine.com/22/aha.)**

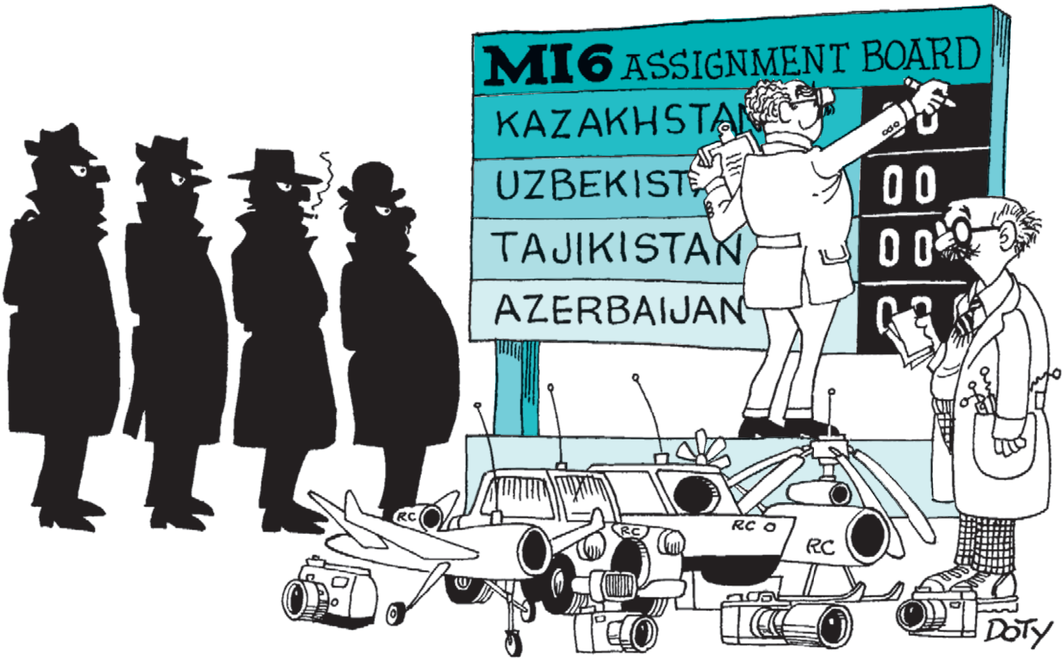


Illustration by Roy Doty

Spy Games

Four spies from MI6, the United Kingdom's intelligence service, were sent out to record activities at four locations in four countries near the Caspian Sea. They set up stakeouts at an embassy, a nightclub, a prison, and an island compound. They were each armed with a different remote control vehicle and had different cameras (night vision, low-light, 100x zoom, and thermal) to complete their mission.

Figure out which country each spy went to, along with the location they were monitoring, and which camera they used, mounted on which remote control drone.

» The island was being scoped by the R/C boat, but not with the night vision camera.

» The embassy being watched was located in Azerbaijan. Agent 005 was not in Kazakhstan.

» Agent 007 went to Uzbekistan, but was not controlling the R/C car. Agent 004 was scoping out the club.

» The embassy was not being monitored with the low-light camera.

» When the spy who had the R/C helicopter realized he couldn't get close enough to the dance floor, he used the 100x zoom camera.

» The thermal camera was used on the prison, but was not mounted on the R/C car.

» Agent 006 was not in Tajikistan. He was scoping the island compound, but not using the R/C plane.

Michael Pryor is the co-founder and president of Fog Creek Software. He runs a technical interview site at techinterview.org.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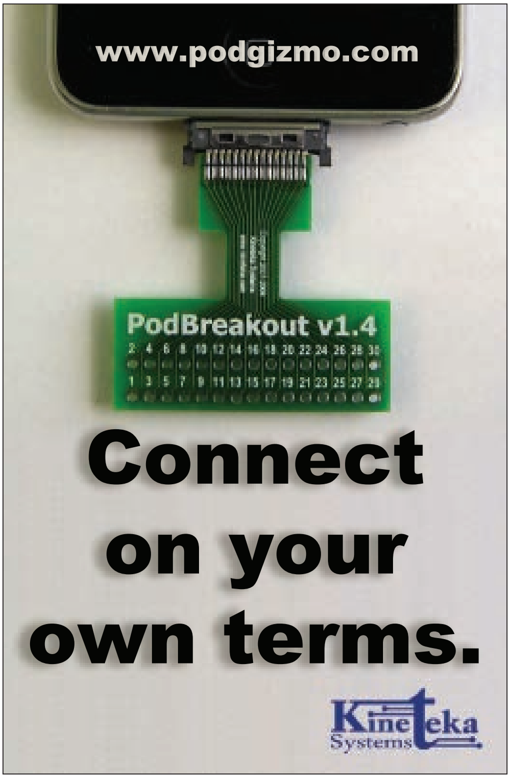
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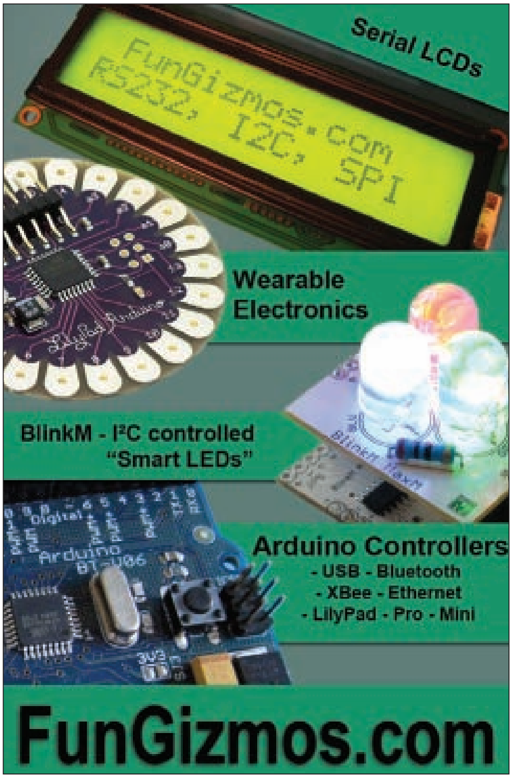
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HOMEBREW

My Servoelectric Guitar

By Keith Baxter

I live near Waukesha, Wis., the birthplace of Les Paul, a pioneer in the development of the electric guitar. Inspired by this fact, I decided to come up with a variation on this iconic instrument.

The fretboard was asking for re-imagining, given that chords and chord transitions are limited for a given tuning; fingers can only reach so far. I tried motors that ran rollers up and down a fretless neck (electronic "fingers"), but was discouraged by the distracting sounds the rollers made during note changes.

An alternative was to change the tension of the strings, but it seemed unlikely that the strings would hold up for more than a few semitones of high-speed stretching. I set about trying to find the "yield point" of a guitar string, the point where tension permanently deforms the wire. I ended up with an old handbook whose data was not at all encouraging.

On a whim, I bought a package of guitar strings to make the measurements myself. What I learned with a bathroom scale and a bucket of sand was that the handbook values are way too conservative for modern guitar string technology, and with a little care, one can coax out a full octave of note changes from standard guitar strings with a re-tensioning range that can be sustained indefinitely.

I was in business. I combined surplus Japanese gearmotors, slide pots from an audio mixer board, screen door springs, high-tension deep-sea fishing line wrapped around the motor shafts, and pulleys made from skateboard bearings, to make a guitar that provides rapid chord changes by changing string tension as you play.

The latest version, shown here, adds an Arduino controller that, over time, learns from its tuning errors to improve its tuning precision and speed, and a special nonlinear spring configuration that improves the tuning accuracy for low notes.

Because the transition between notes is smooth, it has a kind of gliding sound like a pedal steel guitar; but unlike a normal guitar, the notes don't all slide together or in the same direction. It sounds kind of haunting, unambitious, slack, laid-back.

Of course a guitar is not all about sound; it's also about looks. The web taught me how to bend masonite with a steam iron, sand it glassy smooth, and put on a dozen coats of lacquer to produce the familiar glistening curve we associate with this enduring musical instrument.

Keith Baxter is a patent attorney practicing in Milwaukee, Wis. The design for this project is open source and described in more detail at servoelectricguitar.com.

Photograph by Keith Baxter


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