33 PROJECTS: Arduino, 3D Printing, Robots, LEDs

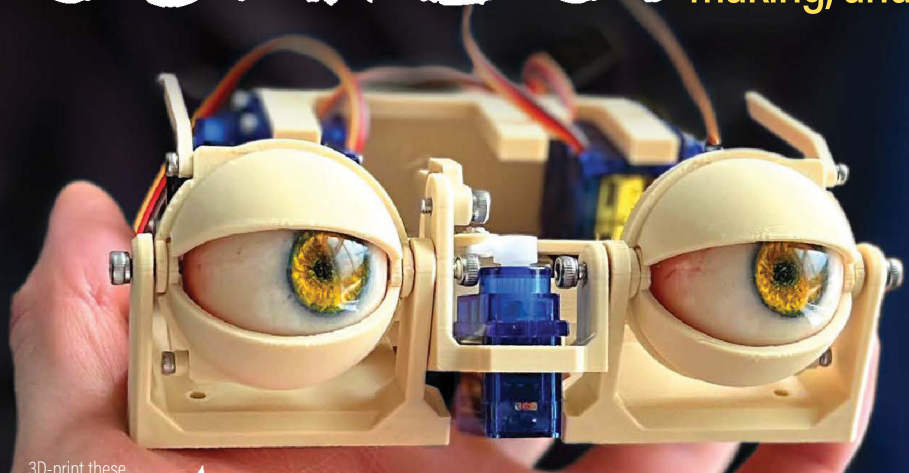
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SEPIA LUX: Kinetic Inflatable Art Car

ANIMATRONIC SCARES!

Bring mechanical characters to life for Halloween, movie making, and live shows



3D-print these animatronic eyes by Will Cogley

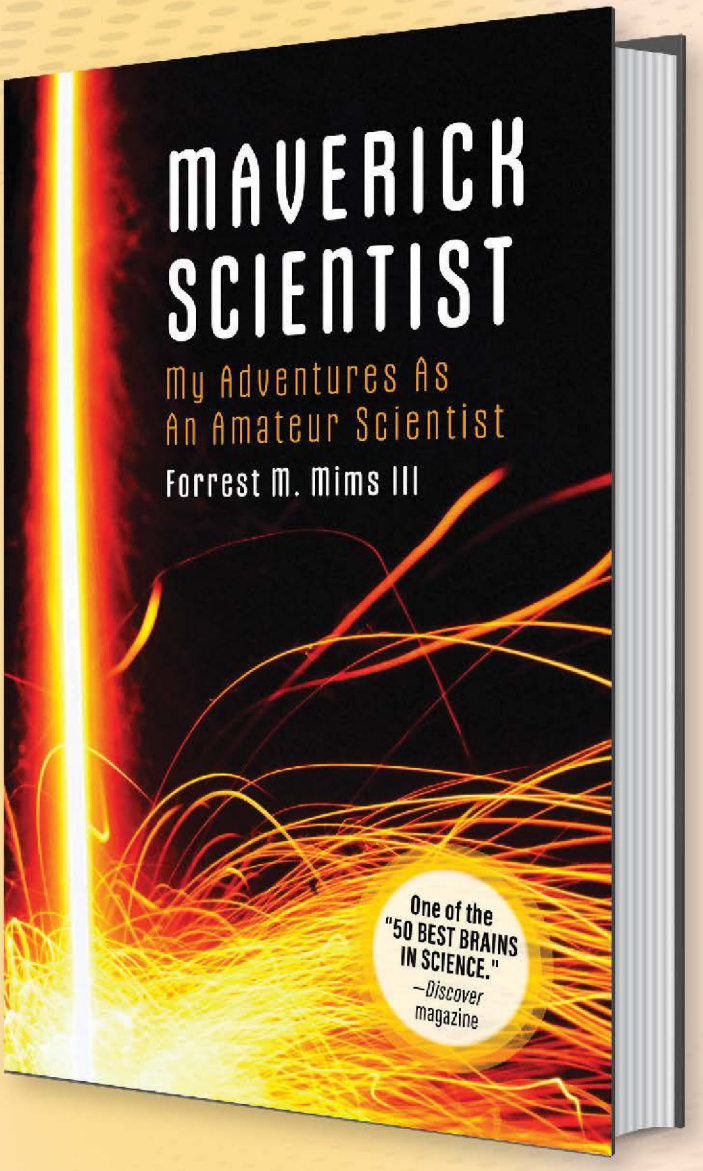
- **Make Realistic Mechatronic Eyes**
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- Breath of Life Mechanism
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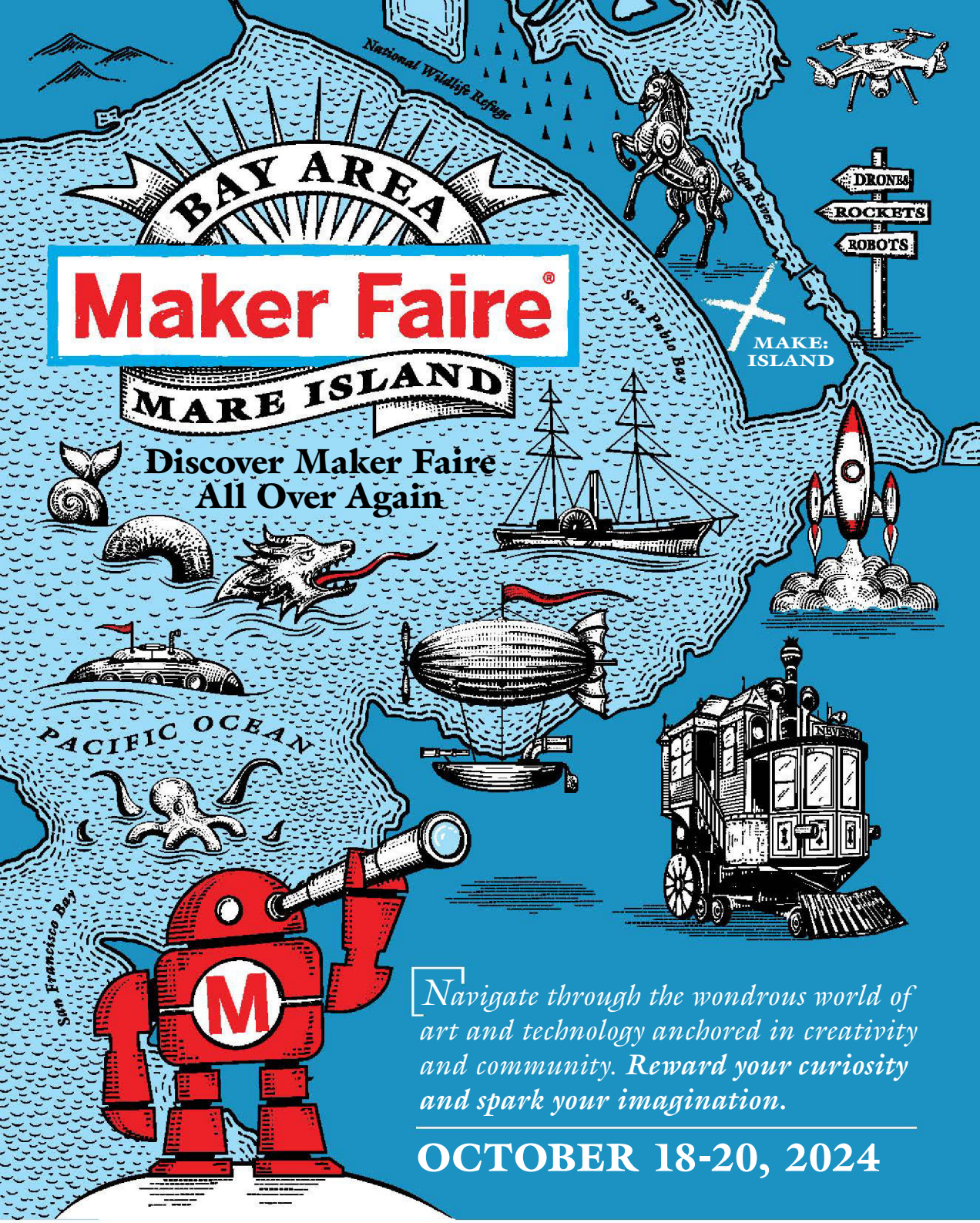
Did you know Forrest Mims is a ...



- Maverick Scientist who **forged his own scientific career** without any academic training in science.
- As a teen, he **invented a new method of rocket control**, and **designed and built an analog computer capable of translating Russian to English**.
- He **created a hand-held radar-like device to guide the blind** while still attending Texas A&M University.
- While in the military, he was **granted special clearance for top secret laser research at the Air Force Weapons Lab** despite lacking engineering credentials.
- He **co-founded MITS** which produced the **first commercially successful personal computer**, and designed the circuit that became known as the infamous **Atari Punk Console**.
- He later **consulted for NASA's Goddard Space Flight Center** and was **given the Rolex Award** for his achievements.

Forrest's memoir provides an intimate look into the scientific community and tells the story of lifelong learning.
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Jesse Velez, Bill Kennedy, VJzoo, Lee Wilkins, Jon Garcia Aguado, Brookelynn Morris, Bob Knetzger

Make:®

"Invention, it must be humbly admitted, does not consist of creating out of void, but out of chaos."
—Mary Shelley

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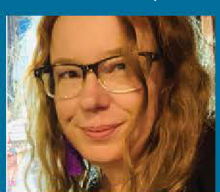
What's your dream Halloween costume?



Evan McMahon
Seattle, Washington (Animatronic Singing Spooks)
Moving Medusa snakes on your head that hiss and track passers-by.



Will Cogley
London, United Kingdom (Simple Animatronic Eyes)
The RX-0 Unicorn Gundam — with full articulation, lighting, and transformation sequence!



Brookelynn Morris
Monte Rio, California (DIY Tortilla Press)
My dream Halloween costume would be the Bride from Bride of Pinbot! I'm obsessed with pinball, and she's an icon. Her techno look is the ultimate.

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FROM THE EDITOR'S DESK

ROBUST REMIX!

[The Nekoosa Mobility Walker] was inspired by your article about an open source, 3D printed mobility walker ["Walk This Way," *Make:* Volume 88, page 100]. My students at Nekoosa High School built this open source walker, with the supplied plans, and they realized that most of the material cost was from the wooden dowels. Initial print-volume calculations and simulation showed my students that they could build an all-plastic walker that was stronger and less expensive. I challenged them to create a strong, 100% 3D printed walker for under $20 material cost.

—Benjamin Peters, Nekoosa, Wisconsin



Read more about Nekoosa High School's Mobility Walker in the *Make Things* newsletter (makethings.make.co/p/20-3d-printed-mobility-walker).

WORTH THE WASTE?

I love seeing all the creativity in *Make:*, it's very exciting to see what people dream up and what new tools are available. However, Volume 88 struck a sour note. I love the idea of multicolor printing, and I realize sometimes "Making" is at odds with an environmental/sustainability lens (do we really need more plastic items, even if they're cool?), but those purge towers on pages 30–31 are something else. If the amount of waste far exceeds the mass of the final product, should we really encourage widespread adoption of these kinds of printer? It was good to see articles on the more "green" side of making, e.g. Precious Plastics and the Pultruder (creating filament from PET bottles) but I would have liked to have seen *Make:* take a stronger stance on wasting plastic.

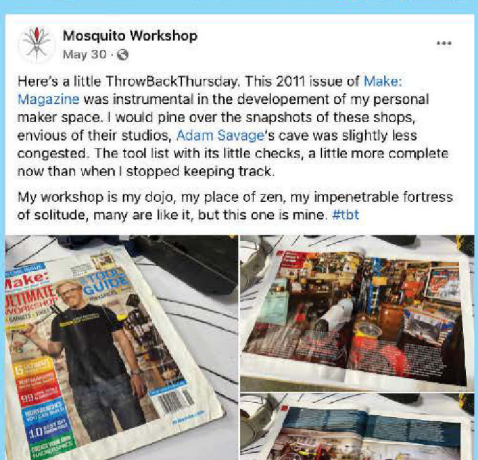
—David Patman, Winnipeg, Manitoba

Editor Keith Hammond replies:

You read our minds, David: thrilled by multi-material printing and horrified by the waste. We hope that by frankly criticizing its flaws we'll spur rapid improvements, like multi-extruders that can eliminate wasteful poops and purge piles.

FROM THE SOCIALSPHERE





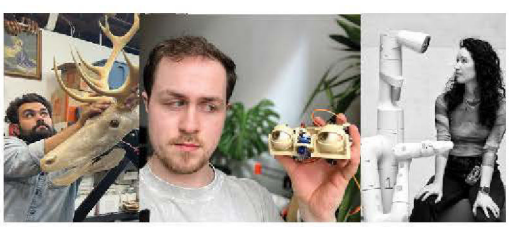
Make Me Believe

by Keith Hammond, Editor-in-Chief, *Make:* magazine

As a kid at Disneyland in the 1970s, my most memorable rides were not the rip-roaring coasters but the immersive fantasies like Jungle Cruise and Pirates of the Caribbean, with their lively animatronic props: a submerged hippo lunges at the boat, mouth agape and ears wiggling; a jailed pirate desperately finagles a mangy dog for the cell keys. These moments are way more than the sum of their parts. Mechanical characters with a few lifelike motions, combined with sound and lighting, can make real magic, transporting us into a fantasy more vivid than any screen.

Pioneered by Disney's Imagineers in the 1950s and 60s, animatronics today is a mainstay of theme parks, moviemaking, and Halloween haunts, from Spielberg's Jurassic *T. rex* to that zombie erupting from your neighbor's lawn. It's a delightful on-ramp to all kinds of making, a techno-artistic mashup where robotics and electromechanical engineering join forces with character design, special effects, puppeteering, and choreography to create the illusion of life.

In this issue of *Make:* we'll show you how F/X pro Jesse Velez designed and built a screamin' demon deer, à la *Evil Dead II* (page 36), and how you can animate simple, glow-in-the-dark ghosts using Bottango animatronics software (page 44), build your own wonderfully realistic animatronic eyeballs (page 54), and give your creatures life with a nifty Arduino breathing mechanism (page 58).



Emotion in Motion

How can robotic movements seem so real? We are social creatures who instinctively understand a vast vocabulary of body language and facial expressions — movements that have meanings. Animatronics is the art of controlling motion in ways that express emotions, intentions, reactions, even humor.

Movement can also evoke feelings beyond any literal meaning. Dr. Catie Cuan is a pioneer in the intriguing new field of *choreobotics.* Trained as an engineer and a professional dancer, she programs robots to perform dance routines that are abstract, graceful, and beautiful. She says the world will need a lot more robot choreographers. Read our interview at makezine.com/go/catie-cuan.

Smooth Moves

What makes today's animatronics so believable is precise digital control of electric motors. In the 1960s they used clunky on-off switches for electric, pneumatic, and hydraulic actuators, but now we can compute complex motions of servos and stepper motors with amazing finesse.

Interpolation is the key, whether we're using powerful software or tiny microcontrollers costing a few bucks. The *ServoEasing* library for Arduino smoothly interpolates movement between two specified positions of a servomotor. Bekonix' drag-and-drop timeline automatically calculates motor fades and transitions. Bottango interpolates between keyframes to create a 3D animation — just like game and movie animators — then maps that over to animate your real-life hardware.

At the other extreme are BEAMbots — simple analog robots with no computation at all. They move autonomously when sunshine powers them, like our Solar Plant Rotator (page 76) that will keep your houseplant well-lighted on all sides.

Third Rock from the Sun

Also in this issue, we explore the frontier of DIY geoengineering with Luke Iseman, who's controversially cooling the Earth by sending SO_2 to the stratosphere, one balloon at a time (page 20). And we launch a new feature on DIY Energy, showing how to hook up small-scale, direct-DC solar power to run your laptop, workbench, and more (page 26). Fantasy is fantastic, but there are lots of fun problems to solve in reality, too.

Jesse Velez, Will Cogley, Chris Michel

MADE ON EARTH



Amazing builds from around the globe

Know a project that would be perfect for Made on Earth? Let us know: *editor@makezine.com*

A CUT ABOVE THE REST

TAMARAKOSTIANOVSKY.COM

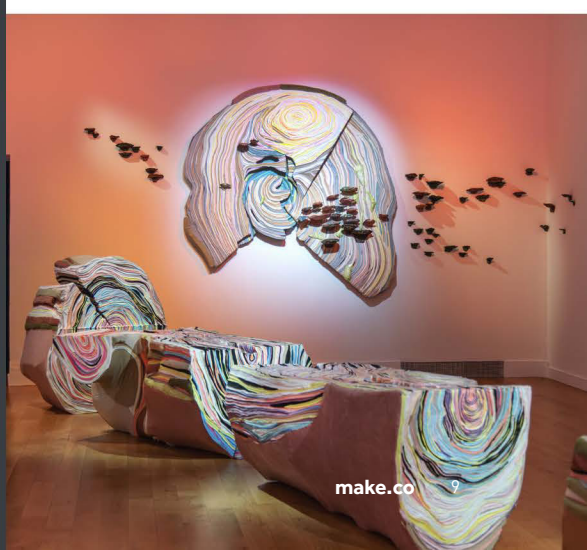
Tamara Kostianovsky's fabric-based sculptures convey all the passions and emotions of a mainstream marble masterpiece and then some, befitting her colorful specialty in the medium of the flesh, dead carcasses, and natural rejuvenation. Kostianovsky, an Argentine-American artist who has presented many solo exhibitions across the United States and Europe, continues to use her formal training from the Pennsylvania Academy of the Fine Arts in her work. Twenty years into a successful artistic career, she maintains that sculpting with fabric is a skill she constantly works to improve. "There isn't really a difference between fabric sculpture and more traditional techniques like marble or bronze," she says. "The laws of visual arts are still the same: to create forms agreeable to the eye, to bring a sense of harmony in a visual format."

Kostianovsky's process usually takes about two months per sculpture, in which a large chunk of time is spent reviewing and reflecting upon an almost-finished piece. "Sometimes in the desire to actualize the initial vision which prompted the work, a few 'mistakes' are made that get corrected over time." Kostianovsky primarily sews with tough polyester-based threads and curved needles used in upholstery and surgery. She typically starts with a hollow structure made from armature wire, producing a base that is tough and easy to shape. Only the top layer is made from fabric, and her primary source of material is women's clothing — often directly cannibalized from her own closet. The choice was deliberate, drawing parallels between the open and raw carcasses made from female clothing and violence against the female body.

While those elements still remain in her work, Kostianovsky has begun filling the gaps in her cloth carcasses with plant growth and natural beauty. "I was prompted by the desire to create images of regeneration that rendered a positive response to the crisis — a type of visual future, even if utopian," she says. "My recent works with carcasses feature outgrowths of vegetation populated by birds, in vivid scenes where the flesh literally transitions from carnage to renaissance." *—Marshall Piros*







Courtesy of Musée de la Chasse et de la Nature, RX&SLAG Gallery, and the artist, courtesy of private collection/Theo Pitout



WALL-E WOOD

Expert woodworker **Peter Vivian** has been a maker for as long as he can remember. Building upon early success in a model-making competition at school, Vivian trained as a technical illustrator and spent the next two and a half decades in graphic design and commercial photography. Yet throughout that time, he yearned to have his own woodworking business, which he eventually launched and ran for 10 years before transitioning to teaching, helping students master the myriad skills he had attained across his career in the form of a university product design course.

Among his hundreds of projects, Vivian counts cartoons that have been presented to King Charles, pieces displayed at the Royal Albert Hall, and regular features in *Woodworker* magazine and associated exhibitions. He has even built his own ash-framed, aluminum-clad car, using tools be built himself, in a workshop that, perhaps unsurprisingly, he also built himself!

The Wall-E project was a request from a friend, after seeing a *Doctor Who* Dalek model and radio-controlled K-9 that Vivian and a colleague made at the university. Despite having access to all manner of tools at home and work, Vivian ended up fabricating 80% of the Wall-E project with a cheap razor saw and a homemade mitre box. Blueprints for a Lego version helped inform proportions, with details garnered from movie stills. The body is a simple plywood box, connected to the head via an articulated, extendable neck, which enables posing. The eyes are formed from polyurethane foam and wrapped in thin strips of black walnut with lathe-turned irises and pupils. The arms, with their accurate inlaid chevrons, pivot as well, with rotating hands and fingers that really grip.

Vivian saved the tracks until the end, expecting them to be the most difficult aspect of the project, but they ended up coming together fairly easily. The rollers were turned on the lathe, with tracks formed from strips of black walnut glued to flexible ply and wrapped around the rollers. A colleague laser-engraved the front panel with the Wall-E font, and all that was left were a few coats of Danish oil to literally finish the project.

Upon seeing Wall-E, another friend suggested that the Iron Giant might make a similarly charming candidate for the obsoletely fabulous treatment, but that's another story for another issue! *—David J. Groom*

Peter Vivian

THE SECRET LIVES OF EVERYDAY OBJECTS

LINKTR.EE/DR.OPERATOR

When I tell people that 3D printing has come a very long way, it's hard to judge just exactly what I mean. But as a child of the 80s, a Transformer seems to me a fitting ultimate test of the quality of 3D printer. **Aaron Leaman,** aka Dr Operator, has been producing delightful, quirky, and unique 3D-printed Transformers for over a year now. A sandwich? A toaster? Adorable.

Leaman, a prolific amateur toymaker, says that on average he spends about 20 hours designing the models in Shapr3D. His latest is Dial Tone, a telephone handset that actually has a built-in Bluetooth module! The PCB, battery, charging port, and mic were harvested from an old Bluetooth handset, and the speaker came from an old headset.

"Dial Tone was a lot of fun to make and easily the most challenging due to the hardware needed, and my complete lack of experience using electronics in my designs," Leaman said.

This series of models is a bit of a testament to the power of little contests within the community. It all started when Printables held a contest to design toy cars and Leaman was looking for a way to stand out with his entry.

"I had designed a simple looking hippie van, but wanted to make my entry stand out and had come to the conclusion that turning it into a Transformer would accomplish this," Leaman said. "The end result was a very crude looking Transformer whose arms and legs were prone to falling off. It didn't come anywhere close to winning, but it was a ton of fun trying to figure out how to turn a van into a robot. Now, I walk around looking at stuff like 'Dude, that frying pan would make a great Transformer.'"

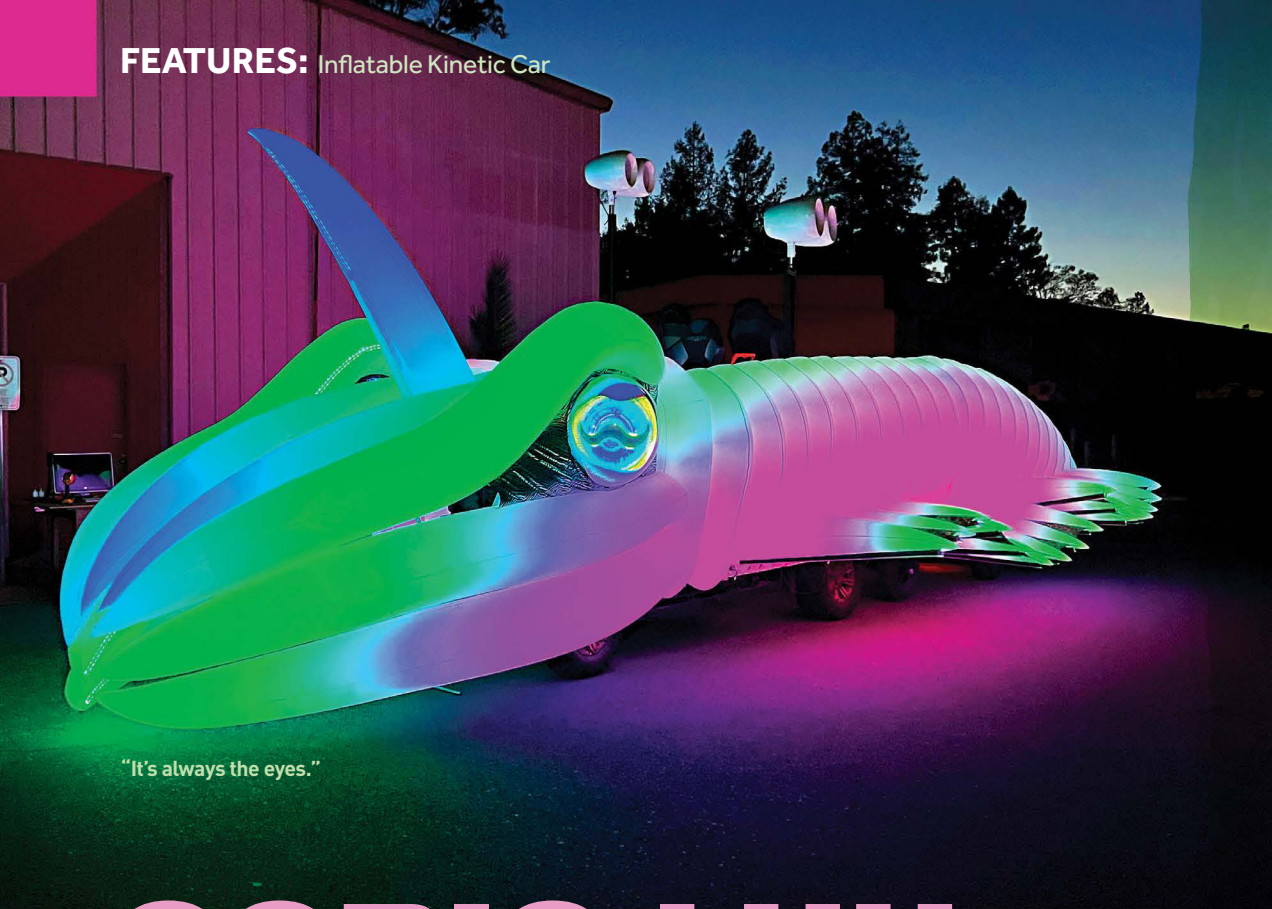
Download the models and print them for yourself at printables.com/@DrOperator.

—Caleb Kraft





Aaron Leaman



"It's always the eyes."

Sepia Lux, The Illuminated Cuttlefish

Written by Dale Dougherty
Photos by Bill Kennedy, Brian Willison and Loren Crotty

DESIGNING THE WORLD'S FIRST KINETIC INFLATABLE FOR A BURNING MAN ART CAR

When Bill Kennedy saw a Facebook post seeking someone to work on an inflatable art car, he replied that he had relevant Burning Man experience earning him the nickname "Inflatabill," which became the name of his own business. By December 2020, Inflatabill's event business had dropped off because of Covid and he was worried about paying the rent on his Santa Rosa, California, workshop. Knowing he needed the work, he drove down to San Rafael and walked into an old airplane hangar. There he saw the project that would occupy him for the next 20 months.

A project manager met Bill and showed him a strange, 23-foot vehicle: a modified Polaris General side-by-side ATV chassis with a trailer. It was the skeleton of an unfinished art car that was conceived to be an illuminated cuttlefish, the so-called "chameleon of the sea" because its body changes color. To bring the cuttlefish to life, the car would need inflatable fins that could move up and down in a wave motion along both sides of its body, and they would need to control the brightness and color mix of the lighting. The head of this cuttlefish would have two prominent eyes and eight or 10 arms.



What Bill saw in the hangar that day was bare bones. The fins were two sets of poles wrapped in pool noodles and attached to cams that would move them up and down. The inflatables, which would fit over the pool noodles, would be lit with LED strips. The project manager explained that the person who designed an inflatable skin for the car couldn't get it to fit. She asked if Bill could sew the existing fabric in place, but Bill said he'd have to redesign the skin — and much more.

Bill learned to work with fabric and sew as a certified parachute rigger. "I was a skydive bum and it's expensive," he said. "To pay for it, I learned to pack and repair parachutes." It was regular work that could be found nearly anywhere in the world, and it funded his avocation. Later he apprenticed for a man who showed him how to design, cut, and sew inflatables by hand,

Bill Kennedy, Adobe Stock-Vector Tradition



The unfinished art car in an old airplane hangar.

before he established his own business. In the late 1990s, Bill went to his first Burning Man and eventually began working on art cars. He fabricated the large dirigible as an inflatable for the Airpusher Art Car.

An Unfinished Art Car

Looking at the cuttlefish skeleton, Bill was told that the build team was gone. "They were a disparate group that was brought in for a particular task and when that task was done, they moved on," said Bill. "That's not how most of the Burning Man art cars are built." None of that team had ever been to Burning Man and they didn't understand what the vehicle would have to endure. "It's a harsh environment that destroys everything," said Bill. "Everything breaks." The art car was built for a patron who interacted only with the project manager, not the builders, and who wanted to ride it around Burning Man.

As Bill did his walkaround, he wasn't sure what to say. "They had already spent so much money on the project and they had a failed car," said Bill. There was a sticker for an approved art car for Burning Man 2020, but that event was canceled because of COVID. The car wouldn't have made it there anyway.

When Bill came back from that visit, he told Brian Willison, who shares his workshop, about what he saw. "This thing's cool," he told him.

Brian, who is a lighting designer, has worked with Bill on many projects for festivals over the years. He joined him on a trip to the hangar. "I walked in and there's this thing sitting there," said Brian. "Of course, I instantly go to the lighting."

He didn't like what he saw. "I see round lights, what are called a PAR because they resemble an old PAR can from the 80s," he said. "They're round fixtures that now use LEDs. They're okay but not very bright, especially for the desert. I see the pool noodles with LED light strips wrapped



Bill Kennedy in his workshop.



Finished front body balloon on table.

Brian Willison, Bill Kennedy

around them." The wiring was a rat's nest of cables, and the controller box was hard to access. Inside, he was surprised to find a proprietary, custom-built lighting controller — not a choice he would have made.

A New Team Takes Over

Two people with complementary skill sets, one more artistic in temperament and the other more technical and curious, but both perfectionists, Bill took on the design of the inflatable skin and Brian the lighting system for the fins and tentacles. They began making regular visits to the hangar together.

"Originally we were under the impression everything was working," said Brian. But they quickly ran into problems with the work the first team had done. "We kept finding so many things they overlooked," said Bill, so the pair ended up stripping the car. "We took all the cables, all the components, all the batteries, everything off the car," said Brian.

On one visit, they found the hangar flooded. Bill convinced the project manager that they should move the art car to his Santa Rosa shop. However, the vehicle was 6 inches too wide for legal transport on the road. Bill wondered aloud why the first team hadn't thought to check that out. "Were they going to haul it to Burning Man as a wide load?" They found a driver to haul it to Santa Rosa on the back of a flatbed truck.

"I learned that the project manager was a sculptor who conceived the project and made a maquette of the cuttlefish," said Bill. "Another guy did a CAD design for it but he told me that they didn't really follow the CAD design closely, and when they made changes they didn't update the CAD model." Bill had to start over and get accurate measurements for the inflatable skin.

As they began measuring the art car, they found that it was not symmetrical. It was like taking over a kitchen remodel from another builder and finding out that the framing was not square, the plumbing fixtures were unusual, and the appliances wouldn't fit in the cabinet openings.

"We just wanted to do what was best for the client," said Brian. "And it certainly felt bad undoing someone's work. But it wasn't ready and it wasn't ever going to work." The good side was they had a lot of creative freedom. "There was a frame and a chassis and a trailer that weren't going to change, but the length of the fins, the length of the tentacles, all of that was up for us to decide."

Their goal was to be ready for Burning Man 2021, but that was also canceled because of COVID. "That gave us a bit of breathing room," said Brian, "to make bigger, major changes that needed to happen."

As Brian took on more project management duties, a third member joined the project in the late summer of 2021. Brian knew that Loren Crotty was looking for work. "I also knew that he has a background in batteries and electric motorcycles. He's also a pretty good fabricator and welder." Loren just did odd jobs at first, but eventually he would take over the project.

The Shape of Balloons

To build an accurate CAD model of the cuttlefish from scratch, Bill used photogrammetry, taking pictures one at a time with his phone and using them as the basis of the 3D model. He also got a CAD file for the Polaris ATV and merged the two.

Having used many CAD systems over the years, from the early versions of AutoCAD on, Bill now works in Rhino with specialized plug-ins. "I use CAD to unfold curved surfaces," he said. "A lot of the technology I use comes from sailmaking. Most people don't realize that sails are not actually flat, but curved. The first flattening software that I used was made for boat builders." Unfolding, he explained, "is taking a curved 3D surface and flattening it down into multiple 2D slices, similar to the way a 3D beach ball is made from a series of flat 2D segments. In the old days, we would start with a clay model, dip it in latex, and slice that latex skin into lots of pieces that we would then literally squish flat and trace to make paper patterns. Now I do it all with software.

"After building a 3D model, I use ExactFlat to slice and flatten the mesh into 2D DXF files. I bring those files into PatternSmith to add seam allowances and alignment notches, and then arrange all the pieces on a virtual cutting table. Once everything looks good, I unroll the fabric onto the 14-foot Autometrix cutting table which uses a vacuum, like a reverse air hockey table, to suck the fabric flat to the surface before a CNC rolling blade cuts out all the pieces. It's then just a matter of sewing all those pieces" — 911 pieces, in the case of the cuttlefish — "together like a giant 3D jigsaw puzzle, and adding air to make it a balloon." Bill refers to himself as a high-tech balloon maker.

He worked on the shape of the balloon, which would fit over the fins like a sleeve. The shape comes down the body vertically, turns out at an elbow, then extends horizontally. Ideally, he wanted the fins to look flat, not ribbed like an air mattress. Bill builds cold-air inflatables, which are more like hot-air balloons than sealed pool toys. He likes to use quiet, lower-power fans to inflate them.

"Once, we took it for a test drive at 5 miles per hour just outside the shop," said Bill. It looked good but the tentacles fluttered. "We had to make adjustments like that," he said.



The camshaft system hardware.

Mechanical Motion

The inflatables that Bill had designed previously were stationary. "This was the first time I had to deal with mechanical motion," said Bill. The cams run down both sides in two segments — one for the ATV body and one for the trailer — and they didn't work properly. "We were blowing out motors," he said.

The poles for the fins were made of metal conduit — too heavy. Loren worked on re-engineering the fins and cam system, along with Skyler Brand, who is a racecar mechanic. They dropped 50% of the weight from the fins and lighting integration. "We were also worried about a bicyclist at Burning Man running into the fins," said Loren. "By replacing the conduit with a composite PVC tube, with a small 12-inch section of 1-inch aluminum at the drive end, we came up with something lighter, and safer, were someone to contact it on a bicycle."

"We got things working," said Brian, "then Bill put some skins on." The fins began pinching in between the cams. "We blew through three or four different kinds of motors."

They changed the drive system from direct drive (gear on gear) to the current chain drive, using high-torque, low-RPM, 24V motors. "Skyler's a real nuts and bolts and gears guy," said Loren. "We did a lot to make the whole cam system robust and avoid all that extra flex in the cam."

"The guys who worked on it before, they're smart guys for sure," said Loren. "But none of them had been to Burning Man — there's zero practicality as far as making something durable." With 11 years of experience at the event, Loren said, "I know the dust and the heat and how it will affect these cams and motors. No way were they going to work for 10-hour shifts in the dirt."

LIGHTING SYSTEM

While Bill shaped balloons, Brian figured out how to control the lighting. To replace the proprietary board, he chose the Falcon F16V3, a 16-port smart pixel controller that costs about $250. He decided on a pixel density of 30 per meter and used MadMapper software to do the pixel layout.

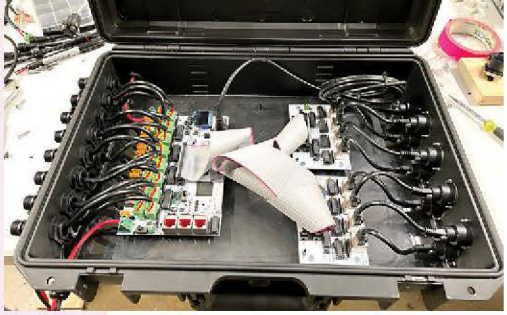
"We went through six or eight different fin designs to see how the lights were going to react," Brian said. One fin was more triangular and thin; another had a little stubbier head. "What we did was put four of them on, side by side, and ran some light tests and shot videos. Some of the lights are up and down. Some are pointing left and right. They all react a little bit differently. Bill and I worked very closely together for several months to get the diffusion right. One pixel was placed on the tip of each fin."

THE EYE

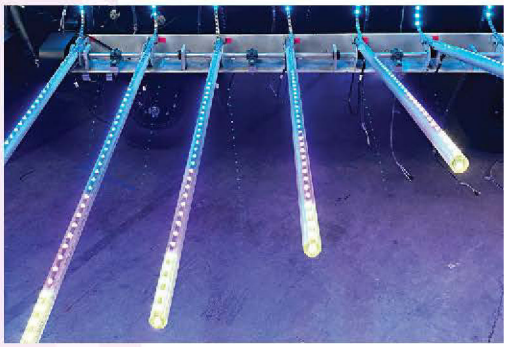
The first idea for the cuttlefish's round eye was to get a large, clear salad bowl, paint it, and use a short-throw projector for imaging. Bill worried that its images would be shaky, but Brian's concern was the bulb. "When you have an arc bulb in a projector, as soon as they get dust on them and they get hot and you try to arc them, they're just going to pop," he said. They agreed LEDs would be better — but they'd need a hemispheric LED screen. "A curvature with LEDs is still hard to find," said Brian.

Brian researched some options from China but was worried about shipping time, and returns, if it wasn't the right solution or didn't work properly. Then he found a company in Roseville, California, and on their website he saw exactly what he was looking for. Almost.

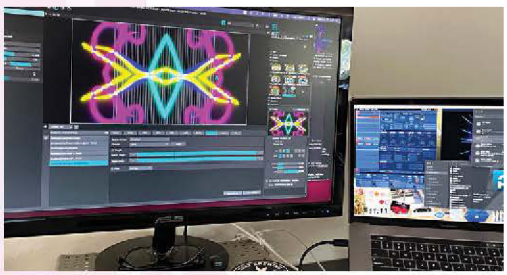
"What they do is globes," Brian explained. "But we didn't need a whole globe; we needed two halves, hemispheres." Each eye has 77,136 pixels



The board on the left is a Falcon F16 V3, a 16-port smart pixel controller.



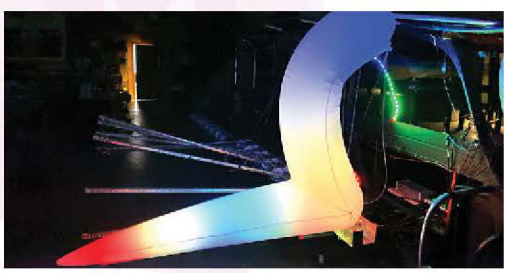
LED light strips on PVC pipes.



MadMapper software used for the color layout.



Different inflatable fin shapes are tested.



Testing colors on single rib.

Brian Willison, Bill Kennedy, Loren Crotty, Alicia Williams

at 2.5mm pitch with 8,000 nits (cd/m^2) brightness. The custom job was expensive, said Brian, but he realized the eyes would be the "cherry on top" of the cuttlefish.

Again he turned to MadMapper. "I can just throw an HD file at the processor and it does all of its work inside and spits it out to the eyes. … I'm able to do the eyes and the lighting show simultaneously where one cue controls both."

Brian also came up with an idea for the exterior of the eye, inspired by a local cannabis club whose designer, Brian Pinkham, had installed a dome-shaped two-way mirror. Bill and Brian liked the idea that during the day, the fish eye would turn into a mirror. *[See also "Welcome to the Mirrordome," page 86.]*

"When I talk to my techie friends and my nerd friends and I show them what we did, it's always the eye," he said. "It's always the eye."

Battery Power

While the ATV is gas-powered, everything else has to run off batteries and generators. The new lighting and camshaft systems changed the wattage requirements. "We were faced with new problems, trying to put our system on top of the original electrical 120V system," said Loren.

"I bypassed the 120V system and I pulled a bunch of current out of the batteries basically to power all of the 12V systems on the car," Loren explained. "We were losing over 60% of our wattage by converting from 12V DC from the battery into 120V AC and then back to 12V DC to power the lights. We were going to need over 2,000 watts for lighting, and we're losing 60% of that wattage because it was done that way." *[See also "DC/DC We Salute You," page 27.]*

Making the Tentacles Move

"I always thought the head needed to move," said Loren. "The fins moved on each side but the tentacles on the head were just sitting there." There are nine arms on the head — three on top and three on each side.

Loren was pushing for robotic movement but Bill thought it might change how his inflatables worked. "There was a lot of fighting about money because so much money had been spent," said Loren. Eventually, the project manager approved.



Testing a projected image on a frosted salad bowl.

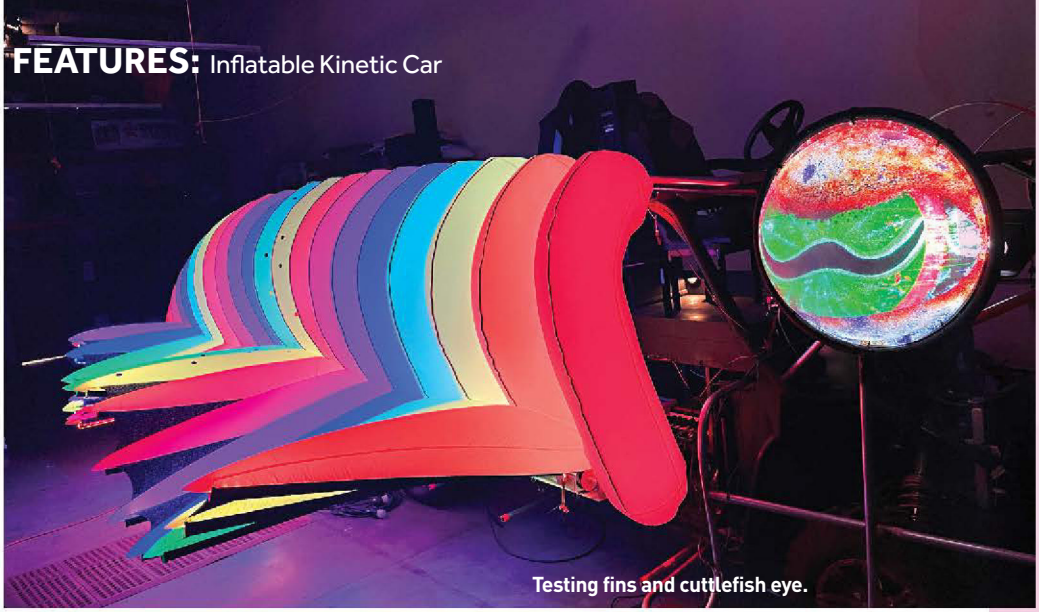


A pair of hemispherical LED eyeballs.



Sepia Lux went back to Burning Man 2023 and will return this year. It was also at Maker Faire Bay Area at Mare Island in 2023 and will be back there again in October 2024.





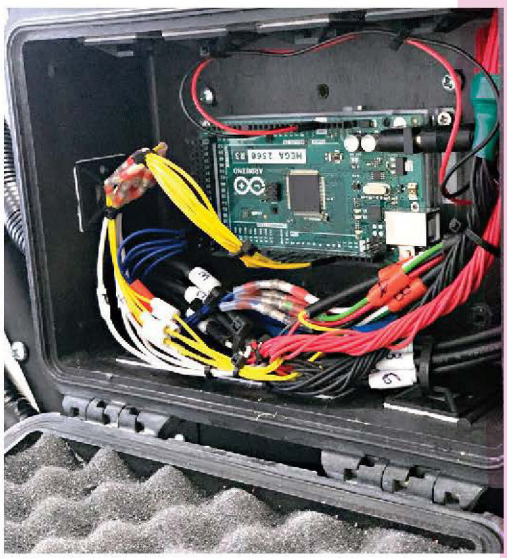
Testing fins and cuttlefish eye.

Brian Willison, Loren Crotty, Dale Dougherty

"I was able to add three linear actuators and power them with an Arduino Nano using a little individual 12V inverter," said Loren. "Then I got it programmed to do two functions, opening and closing." The effect is that the arms open for a person to enter inside and then can gently enclose them.

"That was a huge hit," said Loren. "People loved it." He got approval to upgrade to linear servomotors. "Linear actuators will go from point A to point B at whatever speed they go. A servo can actually go from point A to point B over a specific period of time. I was able to make more complicated functions and then have every tentacle articulate individually." He upgraded to an Arduino Mega.

A final touch was adding a pair of fog machines up front.



Arduino Mega 2560 and electrical wiring in the head of the cuttlefish.

The Wheels

One more problem: it was a rough ride. "The casters were actually bent and broken," said Brian. The trailer weight exceeded their rating. Skyler and Loren tried off-the-shelf replacements before finally ordering custom-made casters. "The ride with the first set of narrow casters was extremely bumpy," said Loren. "We chose a new set of tires that were extremely wide, with a low PSI to cushion the ride."



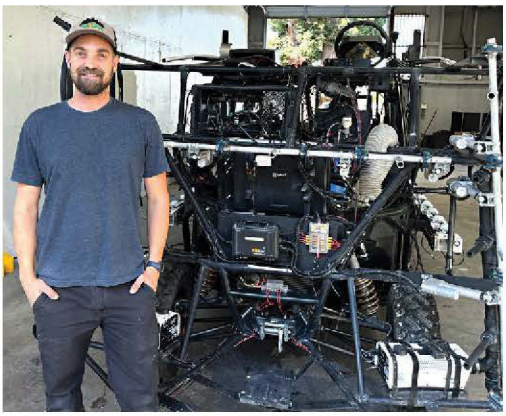
The head and mouth of the cuttlefish.

To Burning Man and Beyond

They had the cuttlefish 90% ready by July 2022. Bill was anxious to be done. He began getting



Completed *Sepia Lux* ready for full test.



Loren Crotty at the front of *Sepia Lux* at his Santa Rosa warehouse.

calls from previous clients. "I was having to turn down some fun commissions so I needed to get the cuttlefish out of my shop."

But first he would give the art car a name. "They were going to call it *Cuttlefish 2020* but that's not how you name things at Burning Man," Bill muttered. He started with *sepia*, the Latin name for cuttlefish, and then settled on *lux*. *Sepia Lux*, an illuminated cuttlefish. "*Lux* not only means light in Latin," he said, but also "lux is a technical measurement of light emitted from a surface."

He went out to Burning Man to see *Sepia Lux* at night in the desert. Viewing it from afar on the playa, Bill said to himself, "Holy cow, we created a low rider for Burning Man — low, long, and sleek." He heard that the patron had a big smile on his face — and he is someone you never see smile. Loren said, "The purpose of the cuttlefish is to make other people happy, and it really did. You could see that."

At the end of 2022, Loren became leader of the project — Captain of the Sepia Lux. After Burning Man 2023, he brought it to Maker Faire Bay Area in 2023 and plans to bring it back in October.

SEPIA LUX: THE SPECS

"The world's only inflated, illuminated, articulated, and animated motor vehicle."
—Bill Kennedy aka Inflatabill

VEHICLE

- Heavily modified Polaris General UTV, 1000cc gas engine
- Lifted, upgraded shocks, upgraded clutch

TRAILER

- Custom 6'×10' steel frame trailer
- 4 custom 360° rotating casters with 10"-wide industrial lawnmower tires
- Max capacity 24 persons

POWER

- 900Ah @ 48VDC lithium battery bank
- Charging via 2 Honda EU3000 gas generators
- 12kW AIMS inverter, 12 circuits of 120VAC

SOUND

- Void Q2 amplifier
- 2 Behringer 15" subwoofers
- 4 Void 12" subwoofers
- 4 Void Airten dual 10" speakers
- 2 Turbosound monitor speakers

LIGHTS

- Falcon F16V3 Pixel Controller board with multiple expansion boards
- 5,000+ individually addressable RGB pixels
- 2 custom LED hemispherical eyeballs with 77,136 pixels per eye @ 2.5mm pitch
- Controlled and mapped with MadMapper
- MIDI control board for manual lighting control
- Wi-Fi iPad interface

INFLATABLES

- Custom balloons designed and fabricated by Inflatabill
- 911 individual pieces of fabric
- 140 yards of fire-retardant PU-coated ripstop nylon
- 5 air blowers (4 @ ⅛HP and 1 @ ¼HP)

MOTION

- 24VDC motors control 4 chain driven cams to rotate 36 fins in a sine wave pattern
- 12VDC linear servomotors and Arduino control motions of head/mouth/arms
- Wi-Fi iPad interface

DUAL FRONT FOG MACHINES :)

HACK THE CLIMATE

You can cool Earth – one balloon at a time

Written by Luke Iseman



Make Sunsets

LUKE ISEMAN is cofounder of Make Sunsets. He (very occasionally) writes at lukeiseman.com and lives mainly around California (Baja and Northern).

It's easy to feel like climate change is too big of a problem for makers to tackle; I certainly felt this way. Yeah, adding solar panels to my RV felt good and helps a bit, but I'm still towing it behind my gas-guzzling F-450. Modern life emits a lot of carbon, and it's not stopping any time soon. Nor is warming: we've only experienced half of the heat we've already baked in with our past emissions. The more I learned, the greater my suspicion that global warming is too great a challenge for makers like me!

I turned to the wrong fiction for a distraction. In Neal Stephenson's *Termination Shock*, a Texan billionaire builds the biggest gun in the world to shoot sulfur dioxide into the stratosphere (20km up). He names it Pina2bo, after Mount Pinatubo. This one volcano released enough sulfur dioxide to drop the world's temperature by 0.5°C for 2 years. I cranked through the book and dove into the science.

The more I researched, the more empowered I felt. Sulfur is cheap and effective: $200 buys you a ton, and if you can get it to the stratosphere it will cool Earth for a year as much as 2 million tons of carbon heats it (see makesunsets.com/blogs/news/calculating-cooling). Chalk dust works too; many other benign chemicals might also be used. But could I come up with a way to get these reflective clouds 20km up to do their job?

In April 2022, I decided to find out. I ordered a $200 weather balloon and $10 of gardening sulfur from the internet. I lit a pile of sulfur on fire and immediately regretted it: sulfur burns to make sulfur dioxide (just like in volcanos), and this reacts with water vapor to produce sulfuric acid. I was breathing small amounts of the liquid in car batteries!

After adding an acid vapor gas mask — and a lid to my burn pot — things got a lot less caustic. I used my trusty 5-gallon bucket vacuum to pump some of the smoke into my weather balloon, and my clouds were ready to deploy. A tank of helium and a few zip ties later, I was ready to launch. With a couple hundred dollars of supplies, I became the first person to intentionally cool earth from the stratosphere!

I decided to give myself until the end of 2022 and $50,000 to convince others to work on this with me. If I couldn't, I'd stop before running out of money or becoming completely obsessed, document my results, and move on with life. I proceeded to talk to many of the makers and founders I've met over the years, trying to get them to talk me out of this. Instead, the opposite happened. Three key things I learned:

1. Nobody had a good reason why this shouldn't or couldn't be done. Speaking with academics who had researched this for years, the only excuse they had for not having already done this was "politics." And the potential consequences? They pale in comparison to global warming: maybe a bit of ozone degradation, but in exchange the ability to drop temperatures by at least 0.5°C (and likely more). As a maker fond of breaking rules, with some room on my credit card and strong opinions on morality, this felt like a perfect project for me.

2. Carbon credits are a big joke. You know those "Click here to plant a tree and offset your flight" banners you see? Most of them result in 0 trees being planted, and yet this is a multibillion-dollar market. People are buying pretend action; this was a low bar against which to compete.

3. Friend of friends help. I'm not exactly what you would call outgoing, so I didn't love talking about my project to random people. But chatting with friends feels great. Fortunately, friends introduced me to their friends. Several awkward calls later, some of these became investors. I (and many of you!) should be more willing to ask for help and introductions; your friends might know the perfect supporters for your project. Mine certainly did!

It's been an exciting 2 years of geoengineering. I knew someone who enjoys selling as much as I like making; it took some convincing, but I got Andrew Song to join as my cofounder. (That's him shown launching the balloon.) We invented Cooling Credits: 1 Cooling Credit = 1 gram sulfur dioxide delivered to the stratosphere, which roughly offsets the warming from 1 ton of CO_2 for 1 year.

Andrew has sold these to 525 true believers, and we've launched 68 balloons to deploy 35,970 Cooling Credits. We've got a long way to go before

we have a meaningful impact on global warming, but it feels great to have started something fundamentally new that needed to be started — a hot opportunity, you might say.

You probably have questions; much of the internet did, too. Tomas Pueyo did the most comprehensive write-up we've found, at unchartedterritories.tomaspueyo.com/p/so2-injection.

And launching the balloons is fun, too. Here's how you can do it yourself!

GET COOL

1. PLAN

Pick a day with minimal winds, definitely under 10mph, ideally under 5. Gather supplies and lay them out neatly (Figure A): knolling is never so useful as when you're trying to manage a 6-foot-diameter, easily poppable balloon.

Put in your launch location at Sondehub (predict.sondehub.org) to plan where your balloon is likely to go (Figure B). If you're in the U.S., notify the Federal Aviation Administration by calling them at (877) 487-6867, after reading the guide at makezine.com/go/filing-a-notam.

2. PREP SUBSYSTEMS

Activate your Spot Trace subscription, make sure you're getting readings from your tracker(s), that it's easy to turn on lift gas, your scale works, rubber bands are not decayed from sun/age, and every part is attached and untangled. You can use our checklist at makezine.com/go/so2-launch-checklist.

3. ADD CLOUDS

Weigh your empty balloon, add calcium carbonate (Figure C), and weigh again (Figure D). The difference is the weight of your clouds.

4. ADD LIFT GAS

This is a bit of an art. Even calm days usually have some wind, so you can't purely go by reading the balloon's pull on your scale. To get exact, you can use a bag of change or something that weighs more than your payload, but so long as you feel it pulling strongly upward, you're probably good.



MATERIALS

- **Balloon** The Kaymont HAB-600 is one of our favorites, with plenty of buoyancy for trackers as well as several hundred grams' payload. Just want to put up a few grams and don't care about tracking? Use any normal latex party balloon (latex biodegrades; avoid shiny, plastic Mylar).
- **Reflective particles** Start with chalk dust (calcium carbonate) for your first several launches, such as Amazon B00GI1UZLY. Only move on to sulfur dioxide (lindeus.com/gases/buy-sulfur-dioxide-gas) with a proper acid vapor mask like 3M's OV/AG P100 Pro.
- **Lift gas** Helium is safer and easy to find: partycity.com/balloons-helium-tanks. Work your way up to cheaper, lighter hydrogen; for repeat launches, you'll want a bigger tank from your local industrial gas supplier (or make your own electrolyzer!)
- **Rubber bands** Size #6 work well.
- **Electrical tape**

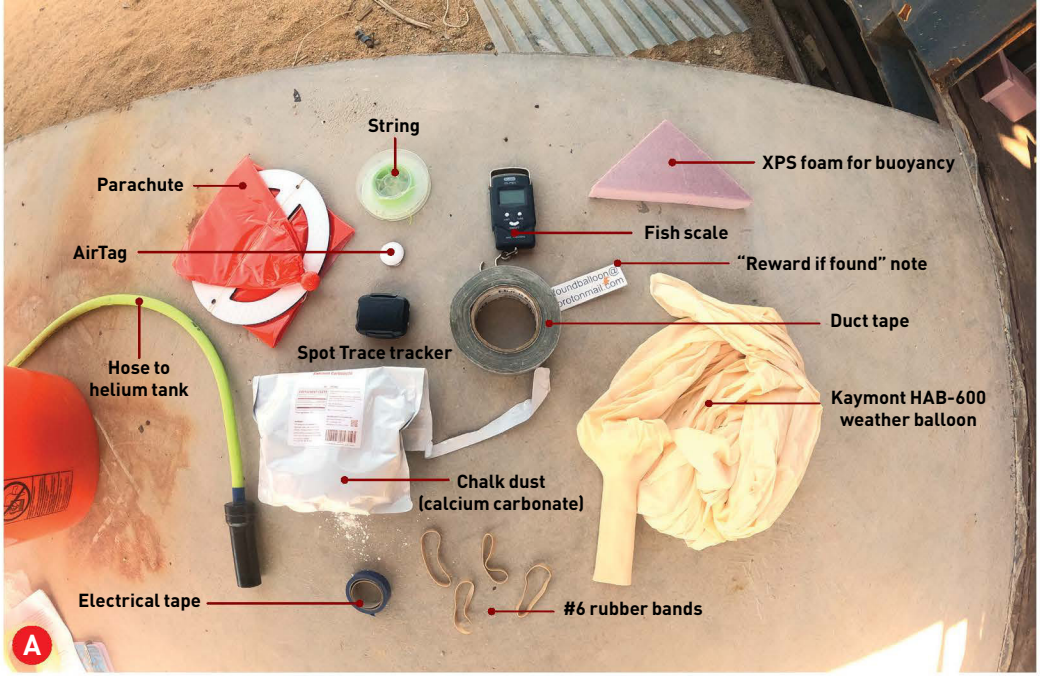
Only once have I had to chase a neutrally buoyant payload down the road!

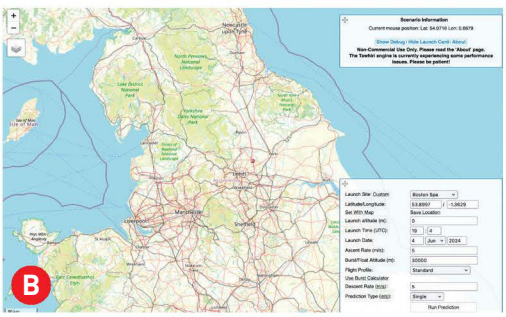
5. CLOSE BALLOON

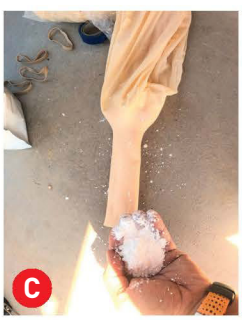
Tie it off with rubber bands and electrical tape (Figure E) and attach the payload if you have one. Bowlines are a great knot for this, and there's a detailed guide at highaltitudescience.com/pages/tying-off-a-weather-balloon.

6. LAUNCH!

Letting a balloon go (Figure F) is even more fun when it's fighting global warming. :)









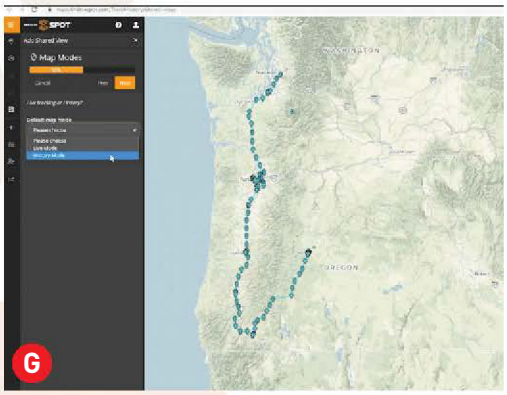




Make Sunsets

7. TRACK

Your Spot Trace tracker should update you on Spot's website as your balloon ascends and descends (Figure G). If you want to start heading to the likely destination, calculate your ascent rate based on your first several altitude and time readings from Spot and plug these into Sondehub. Descents vary, but 5m/sec has served as a good rule of thumb for us.



8. RECOVER

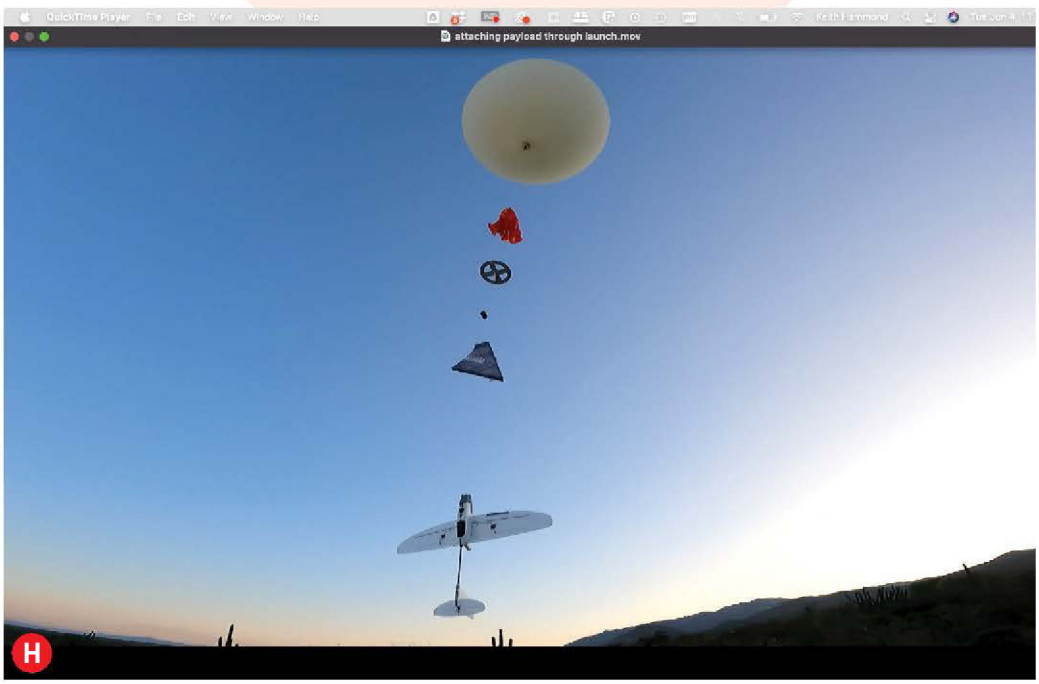
Put your AirTag in Lost Mode, head to wherever your last satellite beacon reading is, and try to get your payload back. Don't be afraid to ask. From "Don't Tread on Me" mountain homesteads to Air Force bases, nobody has said no to us recovering our balloon's payloads. Everyone loves balloons!

GOING FURTHER

After you've gotten good at launching and tracking, here are some challenges you might tackle:

- Making your own hydrogen via electrolysis
- Compressing some of the balloon to control altitude during flight
- Burning sulfur at altitude to produce sulfur dioxide directly in the stratosphere
- Getting your payload to glide back to you (Figure H) on an Ardupilot-controlled RC plane (ardupilot.org) or GPS-guided parachute (makezine.com/go/auto-return-parachute).

If you launch, please let me know how it goes at makesunsets.com/pages/contact. We've learned a lot from other makers about how to get to the stratosphere, and we've got a lot more to learn. Since the Industrial Revolution, humankind has geoengineered a warmer planet with our carbon emissions from burning fossil fuels. Now it's up to makers to cool Earth!



Make Sunsets

TORNADO TECH

Written by Cabe Atwell



The Dominator 3 (left) and TIV 2 (right), in lowered tornado intercept mode, at the National Storm Chaser Summit.

Cabe Atwell, Adobe Stock-liuzishan

Twister chasers and their DIY storm vehicles and science gadgets

TORNADO INTERCEPT VEHICLE (TIV) 2

Owned by Ryan Shepard; developed by filmmaker Sean Casey for Discovery's *Storm Chasers* series
Sponsored by Storm of Passion and Live Storm Chasers, livestormchasers.com/tiv2

- Dodge Ram 3500 with strengthened chassis
- 6.7-liter Cummins turbocharged diesel with propane and water injection
- Armored with ⅛" steel plate, aluminum, and Kevlar composite on 2" square tubing frame
- Bulletproof polycarbonate/glass windows 1.63" thick
- Stereoscopic IMAX movie filming turret
- Hydraulic body skirts to exclude wind from underside
- Hydraulic anchoring/stabilizing spikes to resist wind
- Suspension airbags, two redundant air systems
- 6×4 drive train with front hub lockers
- Intercom with noise-controlled headsets for recording audio
- Siren to warn civilians of tornado danger
- Custom electrical bus, clearance lights, headlights, and taillights
- Safety harnesses and roll cage
- Exit door for every seat position
- Commercial anemometer — fails at 175mph winds — working with Bakersfield College robotics students on custom high-speed version

Parked at an unassuming hotel outside Houston I find two of the most renowned tornado chasing vehicles — quite possibly the only true active armored storm chase vehicles — in the world. These custom, handmade tanks have both been inside tornadoes and left unscathed. They are the TIV 2 and Dominator 3.

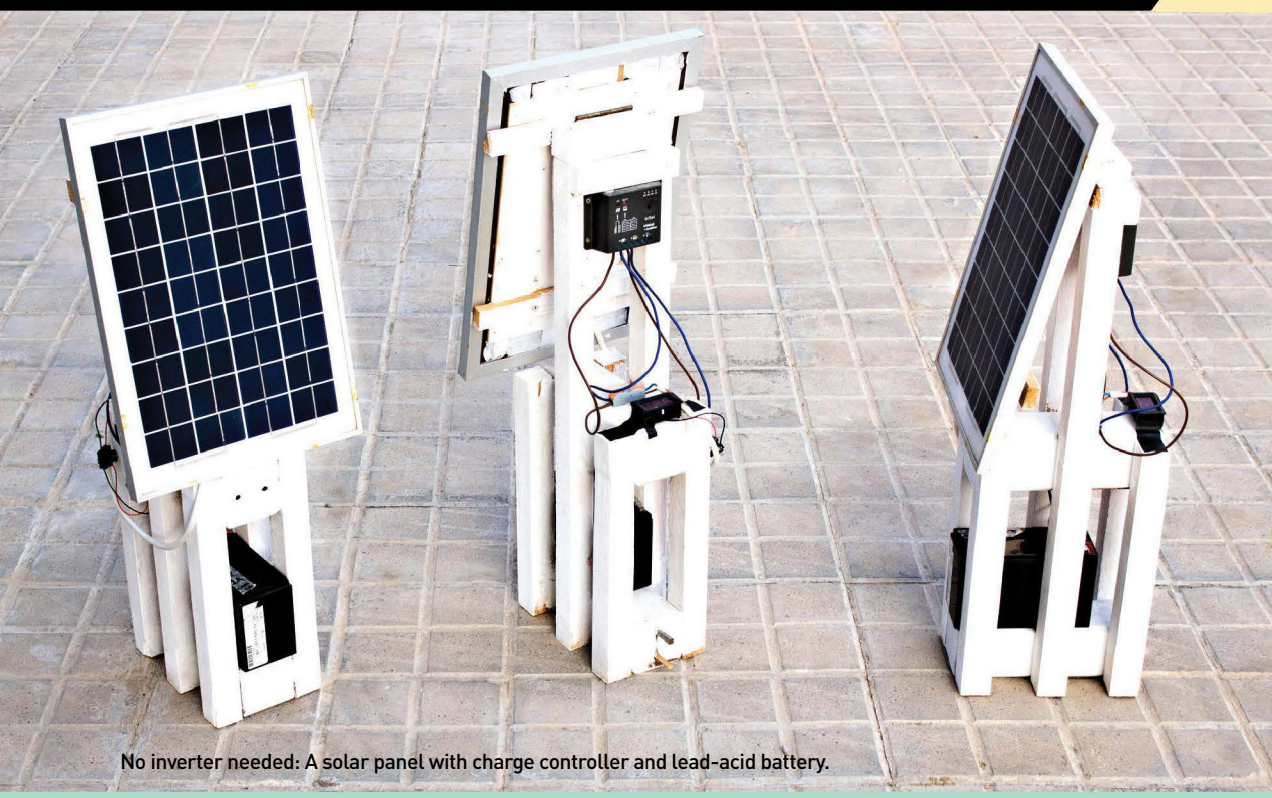
I attended the National Storm Chaser Summit (chasersummit.org) in February 2024 and saw the enthusiasm, the DIY creativity, and the future of storm chasing firsthand. It's action-packed with the maker spirit. It's a lifestyle, a guiding mission — not backed by big funding but backed by extreme passion for the planet's most extreme forces.

As the new sequel *Twisters* hits theaters, I met several chasers who were inspired by the original *Twister* (1996) to join this hazardous hobby. Read my report about the real twister tech and how it works, along with the hands-on history of storm chasing and my adventures at the Summit, at makezine.com/go/twister-tech.

small scale solar

HOW TO BUILD OFF-GRID, **LOW-VOLTAGE DC PHOTOVOLTAIC SYSTEMS** TO POWER YOUR WORKBENCH, LAPTOP — ALMOST ANYTHING

Written by Kris De Decker • Illustrations by Marie Verdeil



No inverter needed: A solar panel with charge controller and lead-acid battery.



KRIS DE DECKER is a Belgian science and technology writer based in Spain. After 10 years in traditional media he founded *Low-tech Magazine* in 2007, where he is lead author and collaborates with designers and artists in building low-tech prototypes, including a solar-powered website and several human power plants. He also works with universities and speaks at tech and sustainability events in Europe.



MARIE VERDEIL is a French designer based in Belgium. Since graduating from Design Academy Eindhoven, she uses design to challenge how we perceive, build, and use technology. In 2021 she joined *Low-tech Magazine* where she is responsible for graphic design, photos and illustrations, and maintaining the solar-powered website. She also collaborates with Kris on low-tech prototypes, manuals, and workshops.

I've built numerous small-scale, stand-alone photovoltaic installations to power *Low-tech Magazine*'s website and office (solar.lowtechmagazine.com). You can build them too, to power a few devices or your whole workbench. This guide will show you what you need, how to wire everything, what your design choices are, how to split power for different devices, and how to charge batteries — or omit them and use direct solar power!

Conventional solar PV installations are installed on a rooftop or in a field. They convert the low-voltage direct current (DC) power produced by solar panels into high-voltage alternating current (AC) power for use by mains appliances, which must rely on the power grid during the night and in bad weather.

None of this holds true for the small-scale systems we build here. They are completely independent of the power grid, run entirely on low-voltage power, and are not powering a whole household but rather a room, a collection of devices, or even a single device. Small-scale solar is decentralized power production taken to its extremes. Like the Slow Food movement, I sometimes call it Slow Electricity.

Most of the work in building a small-scale solar system is deciding the size of the components and building the support structure for the solar panel. Wiring is pretty straightforward unless you want a sophisticated control panel. You only need a limited set of tools: a wire stripper, some screwdrivers (including small ones), and a wood saw. A soldering iron, pliers, and a multimeter are handy, but you can do without them.

Before You Start

SAFETY

Low-power solar systems (12V–24V) are unlikely to electrocute you but they do have risks: electric shock, fire, battery explosion, and component damage. If you stick to some simple rules, you'll be OK. During 7 years of solar power experiments, I have never caused a fire or received an electric shock, although I have fried some components.

- Never touch electric components with wet hands.
- Never touch the exposed part of a positive and negative wire simultaneously. You will become part of the electric circuit and receive an electric shock. It is fine to touch just one wire, or just one battery terminal — but not two at the same time.
- Never let a positive wire touch a negative wire. That will cause a short circuit, leading to physical harm, component damage, fire, or a battery explosion. Use different colors for positive and negative wires and stick to them.
- Always put a fuse in your solar system.
- Make sure your cables are thick enough.
- Never connect a solar panel directly to a battery. Use a charge controller in between.
- Never put a lead-acid battery in an enclosed container; it must be vented.



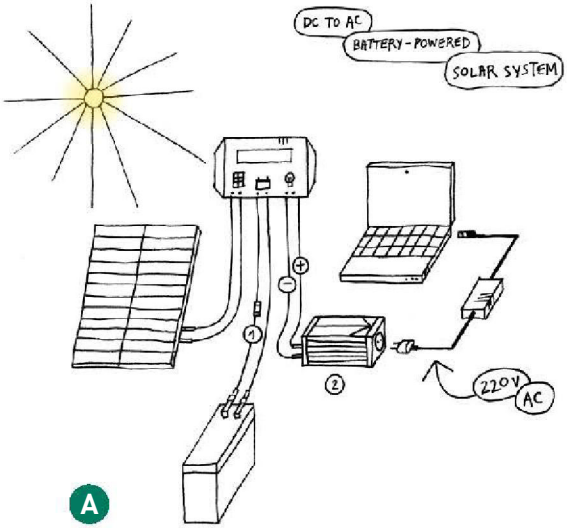
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LOW VOLTAGE OR HIGH VOLTAGE? (DC/DC WE SALUTE YOU)

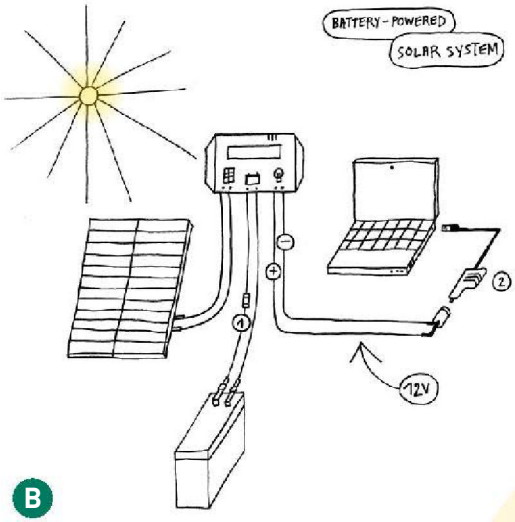
Electric power (expressed in watts) equals current (amperes) multiplied by voltage (volts). So the power we use may be low voltage with a high current, or high voltage with a low current.

Power (watts) = V (volts) × A (amps)

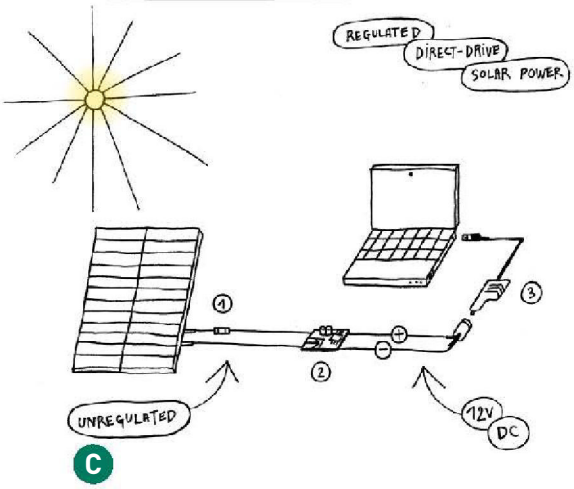
Conventional solar installations for households always use an ***inverter***, which converts the low-voltage DC power from a solar panel into the high-voltage AC power used by mains appliances. You can do the same for a small-scale solar installation (Figure A on the following page) — but it's better to omit the inverter and build a



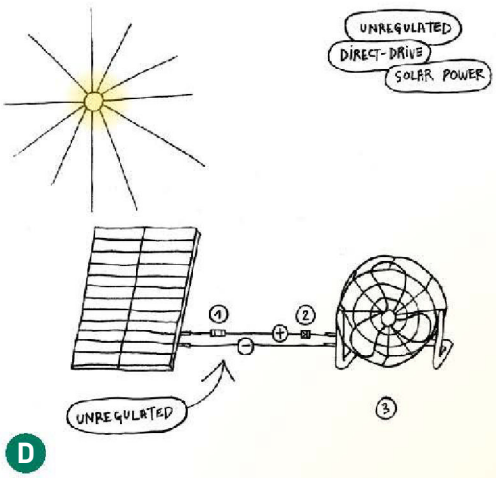
DC-AC: A laptop powered by a solar panel, charge controller, battery, and inverter. 1. Fuse. 2. Inverter.



DC-DC: Laptop powered by solar panel, charge controller, and battery. No inverter. 1. Fuse. 2. Power adapter (12V).



DC-DC Direct: Laptop powered by solar panel and DC-DC converter. No charge controller, no battery, no inverter. 1. Fuse. 2. DC-DC converter (variable input voltage, 12V output). 3. Power adapter (12V).



DC-DC Direct Unregulated: A fan powered by a solar panel. No DC-DC controller, no charge controller, no battery, no inverter. 1. Fuse. 2. Schottky diode. 3. Fan.

low-voltage DC solar system like the ones in cars, trucks, sailboats, and RVs.

Omitting the inverter has lots of advantages. First, it makes solar installation cheaper because inverters are expensive. Second, it makes the system more energy efficient. Converting low-voltage DC to high-voltage AC power involves energy losses as high as 50% for small-scale solar installations. And there are additional losses (at least 5%–15%) in the AC/DC adapters of all those devices that operate internally on low voltage anyway.

High-voltage AC power (110V–120V in the USA, 220V–240V in Europe) results from more than a century of centralized power production. Fossil fuel power plants become more energy efficient as they get larger. Therefore, installing a few large power plants and then distributing the power over large distances makes sense. Because power loss due to resistance is proportional to the square of the current, high voltages are the key to energy-efficient power

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transmission over long distances.

Solar PV power has made this approach obsolete. Unlike a fossil power plant or a wind turbine, a solar panel's efficiency does not depend on its size. And because panels can be installed at the point of energy consumption, there's no need to convert solar power to high voltage and transport it across large distances.

Directly coupling a low-voltage DC device to the low-voltage DC power produced by a solar panel avoids these energy losses and results in a more efficient system (Figure B). You can power the same low-voltage device with a smaller panel.

DO YOU REALLY NEED A BATTERY? DIRECT SOLAR POWER

If you add a battery and charge controller to your solar PV installation, then you can use your solar power when the sun is not shining. However, batteries are expensive, energy-intensive, and have short lifetimes; they account for 80%–90% of total costs and energy invested over the life of an off-grid solar system. They also introduce charge and discharge losses, which have to be compensated for by larger solar panels. For lead-acid batteries, the most cost-efficient option, these losses can be as high as 20%–30%.

Battery storage is handy for some applications, but you can often build small solar installations without storage (Figure C). Such ***direct solar*** or ***direct-drive solar*** systems are cheaper, quicker, and easier to make. They allow you to use a wide variety of appliances during the day — even powerful workshop tools, sound systems, and ventilating fans (Figure D). Money saved on batteries can be spent on larger solar panels, increasing your power supply in cloudy weather.

Direct solar also works great for powering devices with their own rechargeable batteries, such as smartphones, tablets, laptops, bike lights, portable power tools, and power banks. You can only charge these devices during the day, then use them after sunset. Connect a solar panel to a USB power bank (with a DC-DC converter in between, see below) and you've got a lithium-ion battery storage system with built-in power management. If you charge portable LED lights with batteries, a direct solar system can even keep the lights on at night.

What You Need

THE COMPONENTS OF A SMALL-SCALE SOLAR SYSTEM

Solar panels are the main component. For small-scale systems, 12V or 24V is what you want, especially to start with. You can also find small panels with voltages below 12V. Which panels to buy? You have a choice between ***monocrystalline*** and ***polycrystalline*** types; mono are more powerful and expensive. There is little difference between panel brands; almost all are made in China, no matter where you buy them. My advice is to compare prices and buy one that is not unusually cheap or expensive.

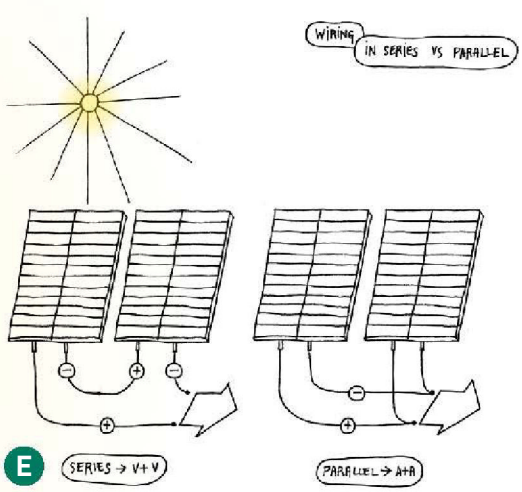
The other components depend on the type of installation you want to build. A solar installation with battery storage also needs a **solar charge controller** and a **battery**. A battery-less, direct solar system only requires a **DC-DC converter**.

Both systems also need **electric cables, fuses,** and **connectors**. Optional components are **on/off switches** and **measuring devices**.

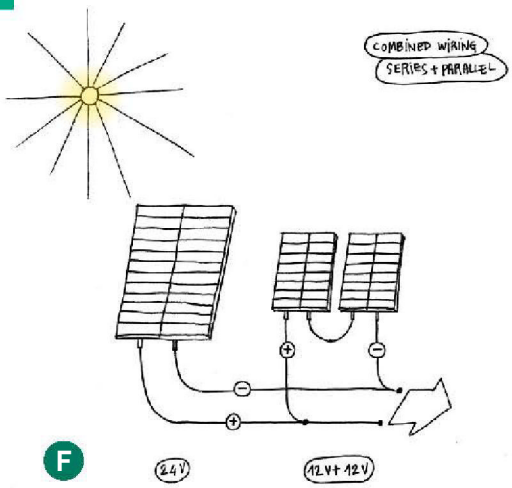
How to Connect Solar Panels

IN PARALLEL

Solar panels can be used individually, or can be connected in parallel or in series (Figure E). When wired in parallel, their voltage output remains the same, but their current output is combined. That's the most common setup. If you need 50W of 12V solar power, you can buy one



How to wire solar panels in parallel (left) and series (right).



F

How to wire solar panels in parallel and series in the same circuit.



G

Different types of solar charge controllers.

50W panel or several smaller ones (two 25W or five 10W) and wire them together in parallel.

Using several smaller panels is not the cheapest option because smaller panels cost more per watt of peak power. However, it might be the only way to fit them where you want; my windowsill is too narrow for a 60W solar panel, but I can fit three 20W panels next to each other.

IN SERIES

You can also wire solar panels in series. Their voltage output is combined, but their current output remains the same. This allows you to power 24V devices with 12V solar panels. Of course, you may just as well get a 24V solar panel. It's best to connect solar panels of the same type, whether you wire in series or parallel. Different types of panels may have different current outputs, which decreases efficiency.

COMBINED SERIES AND PARALLEL

You can also wire solar panels in series *and* parallel (Figure F). For example, you can connect two groups of three 12V panels in parallel, and then wire the two groups together in series. The result is a 24V system with the combined current output of three panels.

You can also wire batteries in series or parallel to the same effect.

System With Battery Storage

To store solar power for later use, you need a solar charge controller and a battery. Most off-grid solar installations run on **lead-acid** batteries. For portable solar systems with batteries, **lithium-ion** is the most practical option. Otherwise, lead-acid batteries are still the safest, simplest, and most affordable option. There are many other less common battery types — **lithium iron phosphate (LFP)** is coming on strong — but I'm not going to elaborate on those here.

SOLAR CHARGE CONTROLLERS

Never connect a solar panel directly to a battery — install a solar charge controller in between. It regulates the voltage output of the solar panel to match what the battery needs during its different charging phases. It also provides a stable 12V output from the battery and shuts down the system if the voltage falls below a determined level. Most solar charge controllers offer a menu to adjust these values.

There are hundreds of different solar charge controllers available (Figure G). For small-scale solar systems, my experience is that anything goes: the cheapest controllers work fine, just make sure they're the correct voltage and have sufficient capacity (see "How to Size a Solar System," below). More expensive MPPT-type controllers aren't worth it for small-scale systems. Lithium-ion batteries need a different solar charge controller, which is more expensive.

BATTERIES

For a small-scale solar system, you need a **sealed lead-acid battery**. If you use a 12V solar panel, you need a 12V battery; if a 24V panel, then a 24V battery. Handle lead-acid batteries with

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care because not doing so can ruin them quickly. Most importantly, their voltage should not drop too much, and you should fully recharge them regularly. *Never leave a lead-acid battery without charging for a prolonged time.* Keep it connected to a solar panel, even when you're away from home.

When coupled to a solar panel and battery, the charge controller will disconnect the battery when the voltage drops below a specified level, usually 12V. You can adjust this value in the menu. You can go as low as 11V, at the expense of a shorter battery lifetime. If you want a longer battery lifetime, you can set the value to 12.2 or 12.5V, for example. The price you pay is a lower energy storage capacity.

Do not place a lead-acid battery in a closed container; it emits hydrogen fumes that must be vented. Put a fuse in the positive wire between the battery and the charge controller, as close to the battery as possible. Monitor the voltage with a digital voltmeter. If you want to know more about batteries, check out the Battery University (batteryuniversity.com/articles).

WIRING

Solar charge controllers connect all the other components: the battery, the solar panel, and the electric load (the devices you will power). The charge controller should have six wire terminals sticking out: two to the battery, two to the panel, and two to the load, usually labeled accordingly.

Always connect the components in this order:

1. Connect battery to controller (battery symbol)
2. Connect solar panel to controller (solar panel symbol)
3. Connect electric load to controller (lamp symbol)

To unplug, you have to go the opposite way:

1. Disconnect the electric load from the controller
2. Disconnect the solar panel from the controller
3. Disconnect the battery from the controller

Never connect the solar panel to the charge controller if it's not connected to the battery. Think of the battery and charge controller as one unit.

TIP: You can avoid costly mistakes by working on solar systems after sunset, or by covering the solar panels during the day.

Direct System Without Battery

In a direct solar power system, there's no need for a battery or a charge controller. The solar panel is either directly connected to the powered device or has a **DC-DC converter** in between. Some DC devices can work on fluctuating voltages, for example, fans, pumps, and other devices with a DC motor; the motor will run faster or slower depending on the voltage. Heating elements can also work at different voltages.

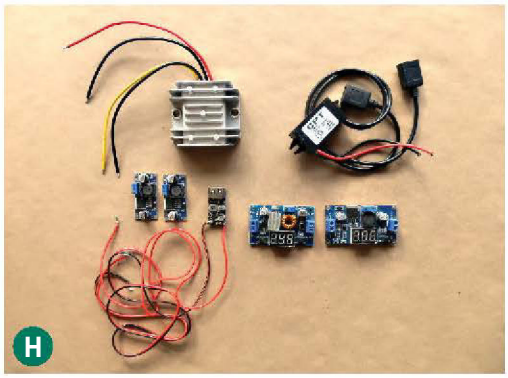
However, other appliances — and all electronic devices — need a precise and steady input voltage.

DC-DC CONVERTERS

A DC-DC converter is an electronic module that converts the input voltage from a solar panel (or other power source) into a steady output voltage for a device, for example, 5V for USB gadgets and 12V to 20V for power tools. ***Step-down*** or ***buck*** converters lower the output voltage compared to the input voltage. ***Boost*** converters ***step up*** the voltage in a similar fashion. A DC-DC converter introduces energy losses, but they're smaller than the losses of batteries, inverters, and AC/DC adapters.

For solar systems without battery storage, you should know that 12V solar panels produce more than 12 volts! In full sun, the voltage output will be closer to 20V. The same goes for 24V solar panels, which output around 32V. The 12V or 24V indication only refers to the type of battery system you're supposed to use it for. Consequently, if you want to run 12V devices directly on a solar panel, you need a DC-DC module that converts the 20V input into a steady 12V output. If you want to run 5V devices, you need a module that has a steady 5V output.

Take care to get the correct electronic module. The most versatile DC-DC converter accepts a wide range of input voltages and converts these into any output voltage you want. This type can be directly connected to a solar panel and power all devices, no matter the voltage they run on; you can adjust the output voltage by turning a tiny screw or pressing a button. Some buck and boost converters have a small digital display that shows



A collection of DC-DC converters.



A 5-watt 12V solar panel with a 12V to 5V buck converter. The connector on the left allows you to quickly disconnect the DC-DC converter and connect the solar panel to a charge controller.

the output voltage (Figure H). Otherwise, use a multimeter to adjust the output.

Other DC-DC converters need a precise voltage input, so they can only be connected to a stable voltage source, for example, a 12V battery. There are also DC-DC converters with a variable input voltage but a fixed output voltage. These can be directly connected to a solar panel (Figure I), but get one with a specific voltage output for the device you want to power.

WIRING

Wiring a direct solar system without battery storage is straightforward. If there is no DC-DC converter, screw the positive (+) and negative (–) wires of the solar panel to the + and the – of the appliance. Put a fuse in between. Optionally, add an on/off button. Make sure the device you power can take the voltage that the solar panel supplies to it, in this case up to 20V.

If you're using a DC-DC converter, connect the + and – of the solar panel to the + and – of the DC-DC converter input. Next, join the + and – of the DC-DC converter output to the + and – of the device. Put a fuse between. Some modules require you to solder the wires to them, while others have screw terminals or plugs. If your converter has a variable voltage output, you can use the solar panel for different types of appliances by turning a little adjustment screw. Alternatively, you can build a control panel to use several devices with different voltages.

How to Size Your Solar System

You need to dimension all the components of a solar installation correctly to work together. That's much easier for a direct-drive solar system than for a system with battery storage.

SIZING A SYSTEM WITHOUT BATTERIES

In a direct solar system, sizing the solar panel is not difficult. You need to match the power production (watts) of the panel to the device(s) you want to charge or power. However, solar panels rarely reach their maximum power, so you should oversize it. Choose one with a power production of double the power use of the device(s) you want to connect. If you want it to work in cloudy weather, make it even larger. A light cloud cover has little effect on power production, while a heavy cloud cover may nearly stop it.

TIP: If you run a laptop directly on a solar panel, know that it will require much more power when charging than when fully charged (or when operating without a battery). A panel may be large enough to power a laptop but not to charge its battery!

SIZING A SYSTEM WITH BATTERIES

Calculating the size of a solar panel for a PV installation with a battery is much more complicated, and brings the additional challenge of picking battery size. A system with a battery will need a larger panel to store extra energy for the night, for periods of bad weather, and for the shorter days of winter. You'll also need to figure:

- The total amount of energy you need: **Energy (watt-hours) = power (watts) × time (hours)**

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- Charging and discharging losses — as high as 20%–30% in lead-acid batteries and around 10% in lithium-ion batteries
- Real battery storage capacity — Lead-acid batteries should not drop below 50% of their maximum capacity; for lithium-ion, that's 15%.

I'll walk you through the calculations, and how to size the controllers, converters, fuses, and other components, in the long version of this article on my site, lowtechmagazine.com/2023/12/how-to-build-a-small-solar-power-system.

Mounting Solar Panels

Small-scale solar power systems can be mobile or stationary. You can mount them on windowsills, balconies, terraces, and patios. You can put them in a backpack and take them with you, or move them indoors near a window.

It's a good idea to fix a solar panel onto a stand. Commercially available support structures often cost more than the panels themselves. That's one reason to make the structure yourself, but another is that it allows you to customize it to a specific location. On my site, I document the (stationary) designs I have made, using mostly scrap wood and metal joints (Figure J). You can also fix panels to existing structures, such as an easel, an old bed frame, or whatever you can find.

The optimal angle of a solar panel depends on the season and location. You can calculate it quickly using online tools such as solarelectricityhandbook.com/solar-angle-calculator.html. For example, for Barcelona in Spain (41° latitude), the optimum tilt of solar panels varies from 26° from vertical in December to 72° in June. A fixed angle of around 40° from vertical is a compromise in which the panels are better positioned for winter than summer.

How to Split Power to Run Multiple Devices

Once you've built a solar power system, you can connect your electric device to it. You may also want a switch to turn the system on and off.

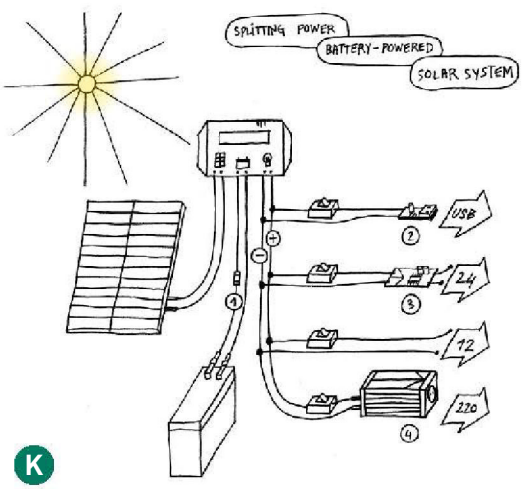
But you may want more flexibility. You may want to split the power to run several appliances simultaneously or alternately on the same solar installation. That's straightforward if all devices run on the same voltage. You only need a connector with two inputs (+ and –) on one side and multiple outputs on the other. You may also want to add on-off switches for each circuit, and/or a switch for the whole system. On the other hand, if your appliances run on different voltages, you split the power and then put the appropriate DC-DC converter in each circuit.

Splitting power works for direct and battery solar systems, but you'll build them slightly differently. When you use a battery and solar charge controller (Figure K), the output voltage is a stable 12V or 24V. If all your devices run on 12V or 24V, dividing power can happen without any DC-DC converter. If you also want to include a circuit that needs a different voltage (for example, 5V for charging USB devices), you can use a DC-DC converter with a stable input voltage (12V/24V) and a 5V output voltage.



J

This panel's tilt can be adjusted and it can turn around its axle.

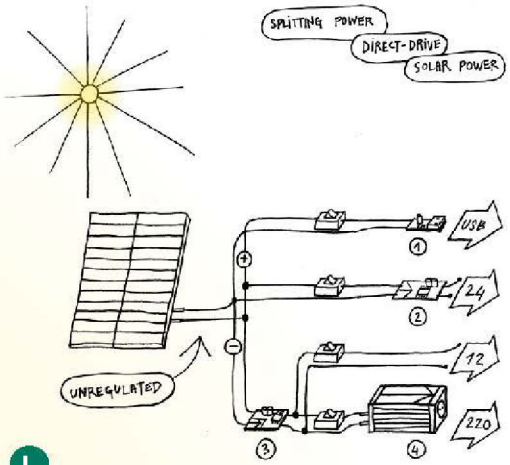


K

Splitting the power of a solar system with battery storage. 1. Fuse. 2. Buck converter (12V to 5V USB). 3. Boost converter (12V to 24V). 4. Inverter (12V to 110/220V).

In contrast, when you use a solar panel directly, the output voltage depends on the solar conditions, and it's often higher than what your devices need. When all your appliances run on the same voltage, for example, 12V, you install a DC-DC converter which accepts a variable input voltage and produces the desired output voltage. Next, you split the power (Figure L). When your devices run on different voltages, first split power and then put a DC-DC converter in every circuit. Divide power again if you want a second output with the same output voltage.

If your solar system has a battery and charge controller, and all your devices run on the same voltage, you can also use typical 12V/24V connectors. You plug them in or out depending on the appliance you want to use. If you have multiple power outlets, you can use several devices simultaneously.

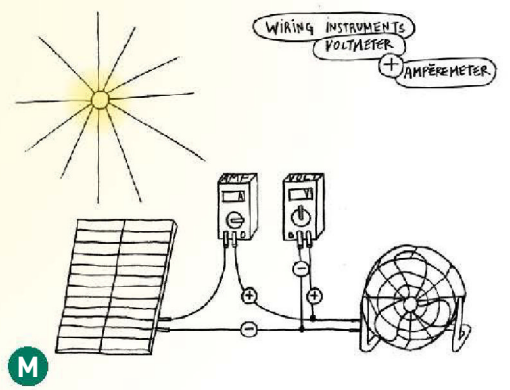


L

Splitting the power of a solar system without battery storage. 1. Buck converter (20V to 5V). 2. Boost converter (20V to 24V). 3. Buck converter (20V to 12V). 4. Inverter (12V to 110/220V).

Measuring Instruments

A solar installation works perfectly without measuring instruments, but they're handy for understanding and maintaining your system (Figure M). They also help you to optimize energy efficiency. To add battery voltage meters, or to add watt, voltage, and current meters to your circuits, read the long version of this article on my site.



M

How to wire a multi-meter to measure amps (in series) and volts (in parallel).

Control Panels and Power Outlets

If you add switches and instruments, you'll want to organize these onto a control panel (Figure N). Also, think about the power outlets. Where do you want to be able to plug in your devices, and what type of connectors will you use? The 12V counterpart of the power outlet is the so-called ***cigarette lighter plug***, but there are alternatives. Add female sockets to your solar system (one for each circuit) and male plugs to all your devices. You can embed the sockets in a control panel too.

The biggest drawback of low-voltage power is its relatively high energy loss during transmission, especially for powerful devices. Therefore, place your power outlets as close as possible to the rest of the solar system. Install multiple systems rather than a centralized system with long cables. Choose thicker electric wires if you distribute low-voltage power over longer distances.

Low-Voltage Appliances

Without an inverter, you need appliances and devices that run on low-voltage DC power. That's not as complicated as it sounds. First of all, many devices are internally running on low-voltage power already: all USB appliances, solid-state lighting (LEDs), other electronics, and cordless power tools (Figure O). Any device with an AC adapter — the counterpart of the inverter — can be plugged straight into a low-voltage network by simply replacing or modifying the power cord. To run a laptop on low voltage, you can just

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replace the standard adapter with one that works on 12V for use in cars. (Or you can set the output of the DC-DC converter to the exact voltage that the laptop needs.) In most situations, there's no need to adapt any of your devices.

In other cases, adjusting an appliance to 12V or 24V demands more work and knowledge. Some devices — such as digital TVs and LED fixtures — have an AC/DC adapter inside, which requires you to open them and remove components. Or you may need to replace an AC motor with a DC motor. Marie Verdeil converted this industrial ventilating fan to work on 1V to 24V, supplying up to 250 watts of cooling power (Figure P). It can be powered directly by a solar panel (youtu.be/iFqzgZPFFX8) or from a battery.

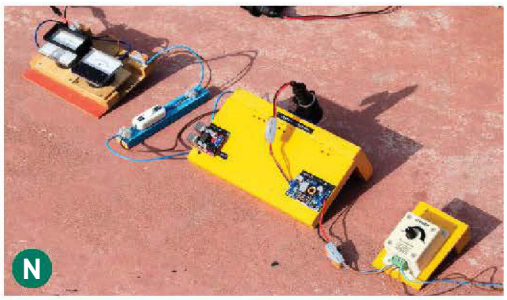
Finally, you can buy a wide assortment of commercial 12V or 24V devices aimed at the users of cars, trucks, boats, and RVs. These range from ventilating fans to electric kettles to refrigerators.

Going Further

Visit lowtechmagazine.com/2023/12/how-to-build-a-small-solar-power-system for more on how to:

- calculate panel and battery size accurately for your needs
- build support structures for panels on balconies, windowsills, rooftops
- include wattage, voltage, and current meters in your circuits
- build tidy control panels with the switches, outlets, and meters you want.

To build your own charge controller, see libre.solar and *Do It Yourself 12 Volt Solar Power* by Michel Daniek, Permanent Publications, 3rd Edition.



A control panel consisting of separate modules. From left to right: multi-meter, on-off switch, DC-DC converters, dimmer.



An old 18V cordless drill with a dead battery, wired to run directly on low-voltage DC power.



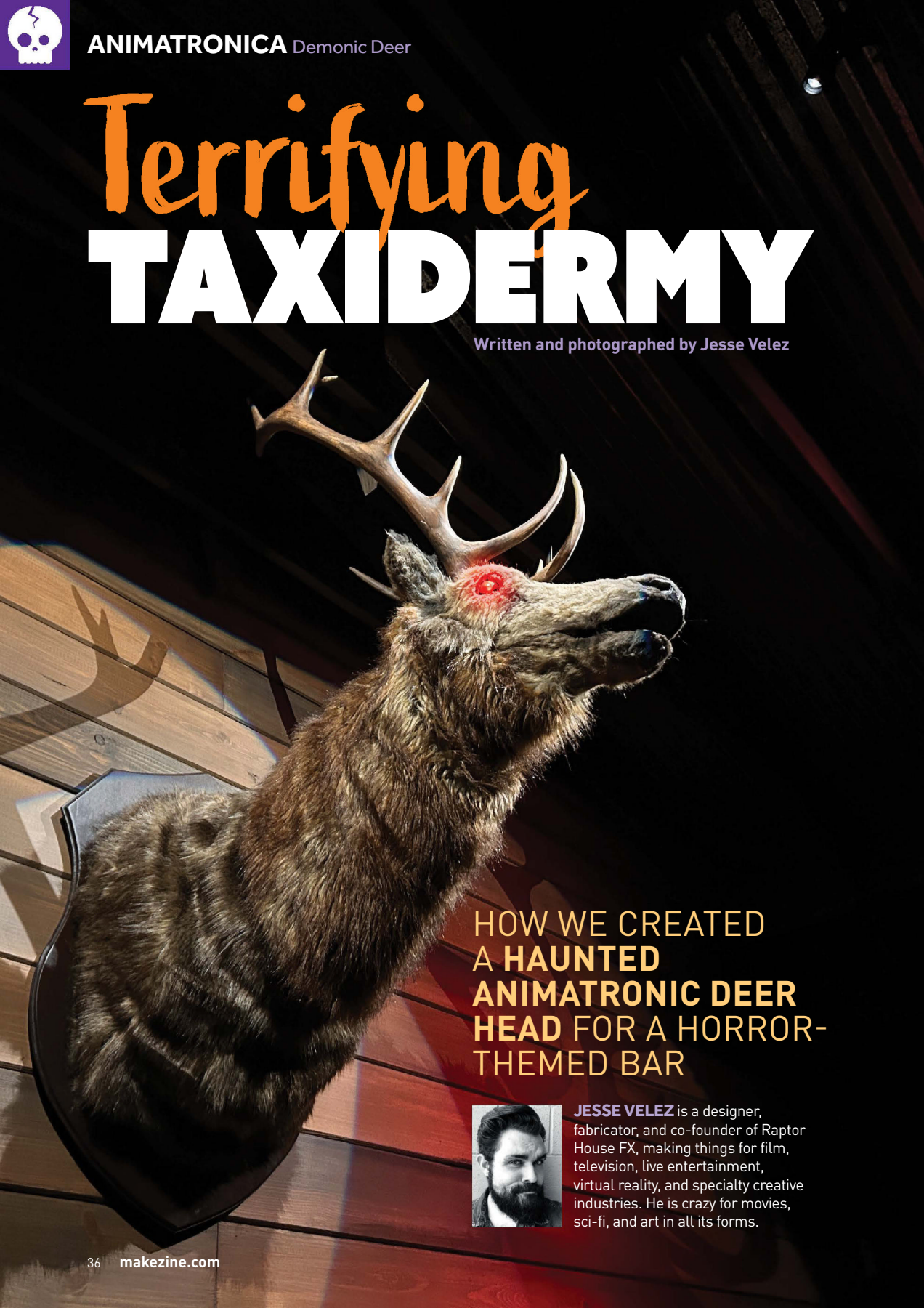
DC motor inserted in place of AC fan motor.



Low-tech Magazine underscores the potential of past and often forgotten technologies and how they can inform sustainable energy practices. Since 2018 it's been running on a self-hosted website powered by a solar panel in Barcelona; since 2019 it has also appeared in print. *LTM* publishes reviews of high-tech "solutions," thoroughly documented articles on historical technologies, and DIY manuals for living a more energy-conscious lifestyle. lowtechmagazine.com

Terrifying TAXIDERMY

Written and photographed by Jesse Velez



HOW WE CREATED A **HAUNTED ANIMATRONIC DEER HEAD** FOR A HORROR-THEMED BAR

JESSE VELEZ is a designer, fabricator, and co-founder of Raptor House FX, making things for film, television, live entertainment, virtual reality, and specialty creative industries. He is crazy for movies, sci-fi, and art in all its forms.

You've stumbled upon an abandoned hunting cabin, deep in the woods, on a dark and stormy night. On the wall above the mantle hangs an impressive stag, long dead and stuffed, his massive antlers covered with cobwebs and dust. You sit down to rest — and suddenly — hear a crack, a creak, a groan, as the static creature above you springs to life. Its glassy black eyes begin to glow with a haunting red light, and its head turns your direction, gaze fixed upon you as it lets out chilling, evil laughter!

While such a scene, as in the 1987 cult classic *Evil Dead II*, can be achieved on screen through the use of manually operated puppets and creative sound editing, doing it in real life is something else. Bringing a mounted taxidermy "demon deer" to life for a live audience can only be achieved through the unique combination of robotics and artistry known as ***animatronics.***

THE ILLUSION OF LIFE

Pioneered by the Walt Disney company for theme park shows and attractions as early as the 1950s, animatronic characters are now a pillar of themed environments and haunt experiences around the world. These machines are capable of a variety of movements and frequently synchronize with audio cues to create a believable moment or scene. Typically these characters are facilitated by an external sound system situated close by, featuring recorded speech, music, or sound effects.

Early animatronic characters were controlled by heavy-duty hydraulic or pneumatic systems, which offered little subtlety of movement or variable speed. Any single movement (the lifting of a finger, turning of a head, or opening of a mouth) was essentially an on/off function. But with enough of these individual on/off functions working in tandem, it was possible for early animatronics technicians to create figures that appeared and sounded convincingly "alive."

Thankfully, consumer 3D printing, modern servomotors and motor controllers, and affordable microcontroller boards have made this previously "industrial" process accessible for anyone with a rudimentary understanding of mechanical engineering, familiarity with simple

Adobe Stock-pixaroma & Vjom, HarshLight from San Jose, CA, USA, CC BY 2.0, via Wikimedia Commons, Dan Harkless, CC BY-SA 4.0, via Wikimedia Commons, Garner Holt Productions

Animatronics Pioneers

Pierre, a talking macaw, is one of 150-plus mechanical singers and performers at Walt Disney's Enchanted Tiki Room, Disneyland's first animatronic attraction, which opened in 1963 and is still popular today. **Disneyland's Audio-Animatronics** were created by electrician Lee Adams, one of the original Imagineers.



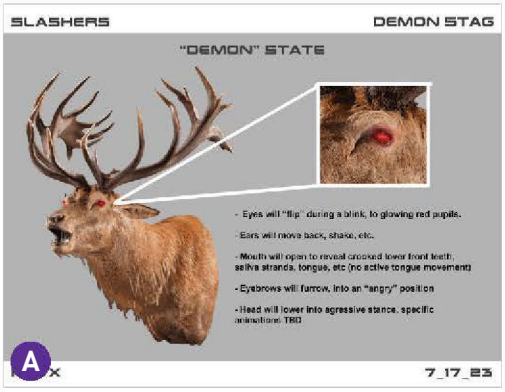


Inspired by Disneyland's Tiki Room and Country Bear Jamboree, Atari co-founder Nolan Bushnell launched **Chuck E. Cheese's Pizza Time Theatre** in 1977, bringing animatronic entertainment to a chain of video arcade pizza joints that would grow to 600 locations worldwide (and inspire the *Five Nights at Freddy's* horror video game franchise). In 2024, owner CEC Entertainment planned to decommission the animatronics in all but two restaurants — then hastily upped that to five after a public outcry.



Garner Holt visited the "Happiest Place on Earth" as a teen and set himself a goal: "On the way home, I told Mom and Dad that I want to build the things at Disneyland." In 1977, still in high school, he founded **Garner Holt Productions**, now the world's leading maker of animatronics for theme attractions including Disney, Universal, NASA, and Chuck E. Cheese. Today he's working to engage students in STEM with camps, kits, classes and "AniMakerspaces." garnerholteducationthroughimagination.com

—Keith Hammond





electronics, and a love of storytelling.

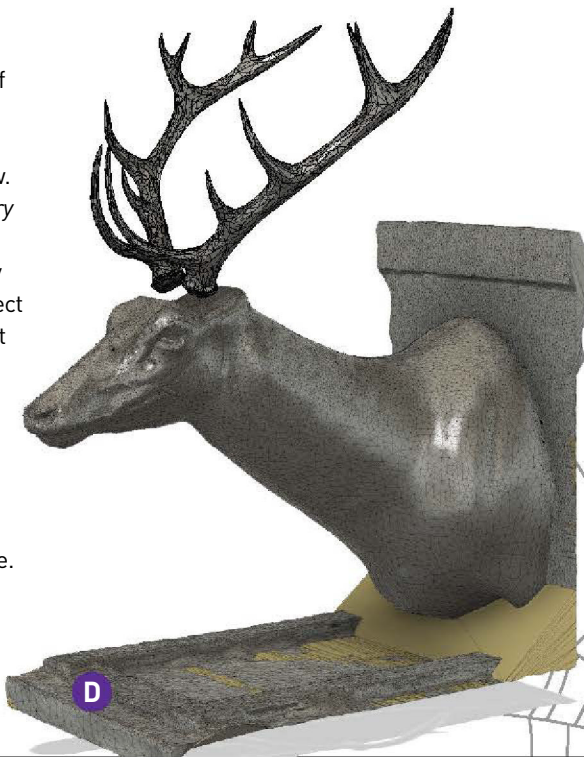
The build I'm sharing in this article was very specifically tailored to our client's needs, but the techniques and principles employed here can be readily applied to any audio-animatronic project you might be planning. Here's how we did it.



THE JOB

For this build my team was asked by the client, Slashers Axe Throwing & Ales, to create an animatronic deer head à la *Evil Dead II* (Figures A and B) to act as a centerpiece above the bar at their new location in Costa Mesa, California. Nicknamed "Bruce," we wanted this piece to appear as a real taxidermy mount with no indication of its show abilities until, at the top of every hour, the lights would dim and he would come to life, seemingly possessed by a devilish spirit, laughing maniacally at the patrons below.

When we begin a new animatronic build, *story is everything.* What is the story you are trying to tell or support? No matter how skilled you may be as a mechanical engineer, if a motion or effect distracts from the desired overall scene, it's not right for the project. Always aim for reduced complexity, especially when a piece is meant to run for years with little to no maintenance.



SIZE AND SHAPE

When creating an animatronic character, early consideration should be given to size and shape. How big will your finished piece be? How much space will it need to move freely? How will it be mounted in position? Every mechanical need will derive from this information.

Since Bruce was going to replicate a real

animal, we started our design process by sourcing a pre-made taxidermy form to determine his exact dimensions. Clay, foam, or even cardboard can be used to mock up a body form before starting mechanical design (Figure C).

Once we had this form, we 3D-scanned it for our "skin" shape for digital design. Working to real-world scale from the start saves time and dollars once parts need to be fabricated, or hardware needs to be selected and ordered. This 3D mesh was imported to Autodesk Fusion 360 and I was then able to model the mechanical assembly within that shape (Figure D).

We use an app called Polycam for all our in-house scanning. Extremely useful, precise, and runs on an iPhone! [*See "Start Scanning" and "3D Scanning Artworks" in* Make: *Volume 84.*]

DETERMINE YOUR RANGE OF MOTION

Our first step in designing Bruce's motion was to determine the precise number of movements the robot would be capable of — often referred to as ***articulation points.*** A simple character can be created with only one or two points of articulation (many of the characters in Disney's Pirates of the Caribbean ride have only one animated component), while complex characters may have upwards of 20. For a project like this, every powered movement adds dollars to the budget. Remember, animatronics can always be *more* expensive, so err on the side of minimal powered movements.

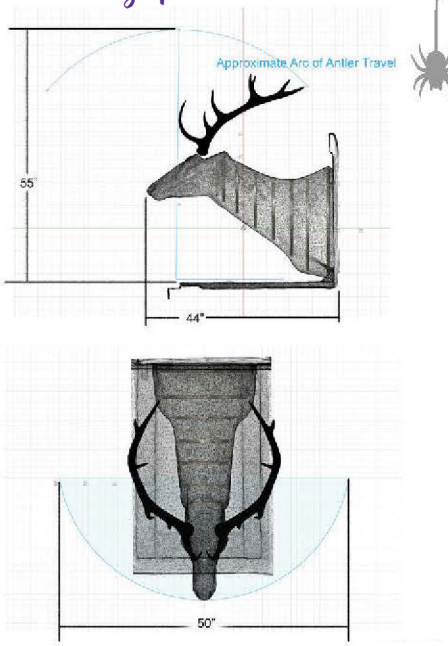
For our purposes, Bruce needed a minimum of three points of articulation to sell the desired effect:

1. Neck, large side to side motion: moving the head back and forth and bending the neck
2. Head, up and down: tilting from a pivot at the base of the "skull"
3. Mouth, open and close: opening the jaw to a realistic degree.

Given more working time and a higher budget, additional motorized movements to the ears, lips, brows, and tongue could be added.

For each of these operations, it is important to physically limit the maximum range of movement in each component. This way, if a motor malfunctions or loses power, the assembly won't be able to damage itself. The neutral position of an installed animatronic should be balanced in a way that does not stress the motors when the components aren't in motion. This is especially true when your project is using servos to drive movement. The lifespan of servomotors, using assigned PWM input, is dramatically reduced when forced to hold a specific position under load.

Slashers Stag Operational Dimensions



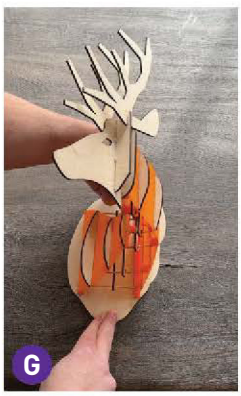
MAKING USE OF FREE ANIMATION

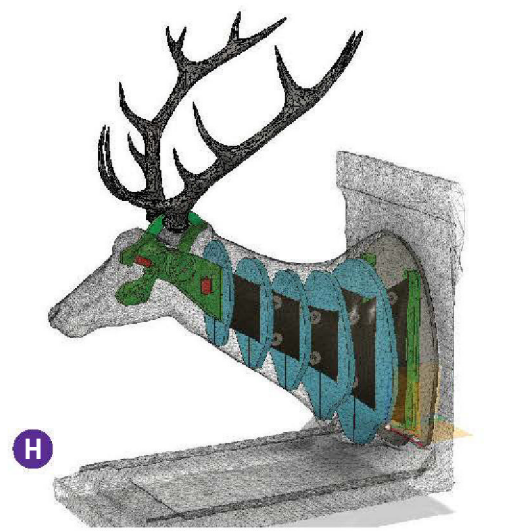
Whenever it supports the storytelling, we try to make intentional use of ***secondary animation*** (sometimes referred to as ***free animation***) in our puppet or animatronic builds. This is extra visual movement that does not require additional powered input. Examples include hanging fur, springy antennae, feathers, fabric, or clothing. Jim Henson's Muppets often use free animation to give added life to the characters: Big Bird's head feathers wiggle in response to every movement of the puppeteer's hand inside his head, giving added personality and visual interest to his performance.

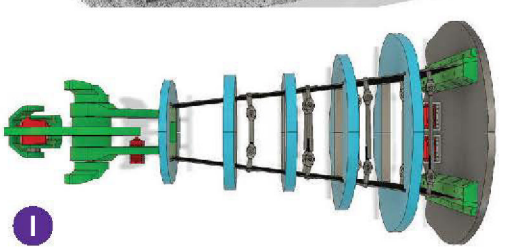
When designing Bruce, we intentionally modeled him after an English red stag, with a large neck mane of longer fur that would add movement and lifelike believability to the final











Ben Eadie

piece without adding mechanical complexity (Figure E).

PROTOTYPING IN MINIATURE

I highly recommend small-scale tests of any mechanical movement before jumping into the final build. This can be as simple as pivoting cardboard mockups held together with brass envelope pins, or 3D-printed and laser-cut stand-in parts as shown in Figures F and G.

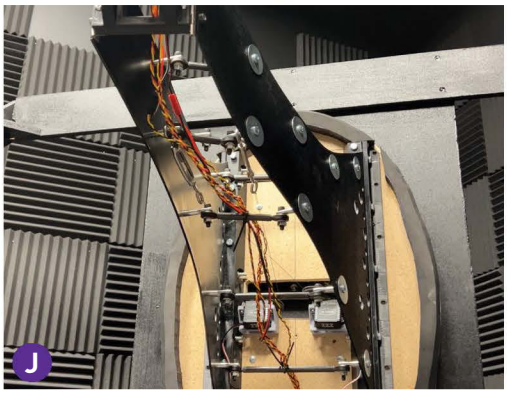
BUILDING A SKELETON

The neck structure and movement mechanism for Bruce was designed by Ben Eadie, freelance SPFX designer in Calgary, Alberta, Canada. For a large taxidermy mount, we needed a flexible design solution that could also handle a significant weight load. While the build was very lightweight overall, the large size, and the long "cantilever" from wall mount to nose, meant that the point at which the head rested on the neck would experience significant weight.

Ben settled on a unique design in which the neck structure was made up of two parallel flexible planes connected with free-moving pivots mounted between and perpendicular to the neck planes. This created a bendy, compliant structure that would hold a constant level position for the head, and keep the head facing forward while it moved side to side.

Once this problem was solved in miniature, it was time for final material selection. For vertical rigidity and maximum "bendability" we went with ⅛"-thick ABS sheet for the neck planes, laser cut to shape. The pivot struts between the neck planes were made of carbon fiber tube, epoxied to ball joint rod ends bolted to eye nut hanger pins, which were in turn bolted through the neck planes. These components were fixed with nylon locknuts, leaving room for free movement in the ball joint ends (Figures H and I).

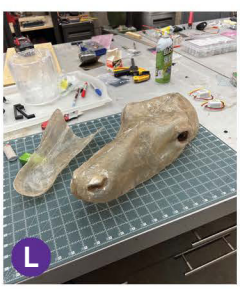
The neck motion is driven by two high-torque servomotors mounted inside the neck, up against the wall mount. These work in opposition to "push and pull" via high-strength monofilament, attached via cable tensioners to the farthest pivot strut. The cables are crossed to the opposite side of the neck, so that when the right servo pulls, the neck bends left, and vice versa (Figure J).





Once this system was tested and final assembly was complete, we used 1½"-thick L200 EVA foam to create the "ribs" that would fill out the body shape under Bruce's fur (Figure K). The profiles for these shapes were made in Autodesk Fusion 360, and exported as flat SVGs at full scale, so they could be traced onto foam for bandsaw cutting.

The skull and jaw shells were made with fiberglass and standard laminating resin, molded off of the same taxidermy form we used for the digital scan (Figure L). Fiberglass is commonly used for animatronic shells due to its compliant rigidity and relatively low weight. 3D-printed antlers (Figure M) were affixed to the skull via threaded passthrough flanges, with ¼-20 all-thread embedded 5" into the antler base.





MOTOR, AUDIO, AND LED CONTROL WITH BEKONIX

Programmable motor control for animatronic systems has been painfully clunky and tedious until recent years. Makers who are familiar with video editing software such as Avid and Adobe Premiere, or audio edit suites like Audacity, will be relieved to learn that timeline-based editing for motor control is finally here, and extremely accessible.

For this project, we partnered with Nicole Shuman at Bekonix, to test their incredibly versatile Bekonix Connect Controller board and help iterate new applications for their product line. While Bekonix is built for enterprise-scale smart tech, the incredible range of functions built into their Connect Controller, and the Bekonix Designer platform, make it an excellent choice for projects with tight deadlines and uncertain parameters. Being able to make adjustments on the fly and integrate new components as needed allows work to progress without a complete design or fabrication plan in place. With one controller board, we were able to store and replay motor animations, the show audio, and the LED effects in Bruce's eyes.

CHOOSING YOUR MOTORS

With any robotics project, proper motor selection should be a primary consideration early in the process. For Bruce, we used programmable metal gear servos from Reefs RC, in two sizes. Two 777 series servos (capable of 700oz of torque at 12V) worked in tandem to drive the neck movement. A third 777 mounted inside the base of the head, on the neck end plate, controls the up-down movement of the head via a push rod. Lastly, the jaw open-close is powered by a smaller Reefs RC 99 Micro (Figure N on the following page).

For each of these operations, we manually measured the power it would take to move each component by using a simple force gauge, and in turn selected motors that would exceed those estimated forces by at least 50%. All motors connect via standard 3-pin servo cables to the Bekonix board.

Accessible Animatronics with Bekonix

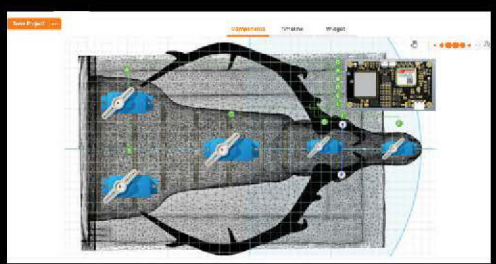
By Nicole Shuman, product manager, Bekonix Inc.

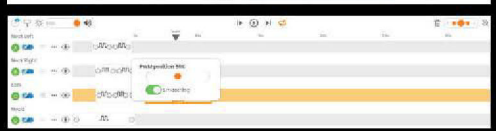
At last year's Maker Faire Bay Area, Bekonix unveiled our new **Bekonix Connect Controller** board, featuring "Inches-to-Anywhere" connectivity.



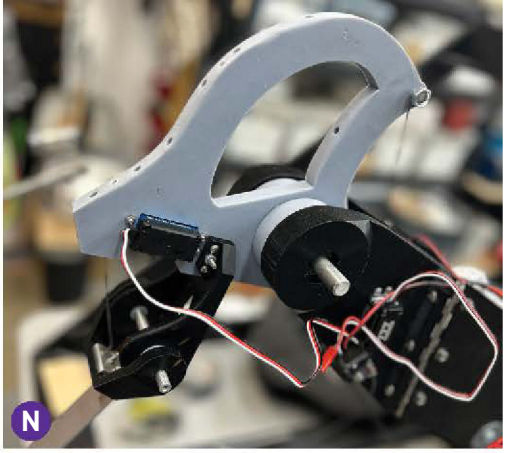
- nRF52840 ARM processor, 16MB flash memory
- Connectivity: Cat-M1, NB-IoT, GPS, NFC, LoRa, BLE
- Onboard temperature sensor
- Stereo audio: 3W amplifier, 32 tracks with audio out
- Compatible with off-the-shelf sensors, actuators
- High-density connectors for board expansion

Combined with our innovative no-code, drag-and-drop **Bekonix Designer** platform, it's a great solution for an animatronics project like this one. ***Digital twin*** technology allows you to upload your project image and build away, using off-the-shelf LEDs, sensors, actuators, and more. Use the ***timeline*** feature for in-the-moment iterations to fine-tune the mechanics and component behavior. Save your project and drag-and-drop it onto your Bekonix Connect Controller, where it will boot up automatically or on a schedule (even timecode).





Bekonix provides a complete communication infrastructure, including edge computing, AI capabilities, and an IoT cloud backend, making it a comprehensive solution for smart devices. We even have a mobile app to keep you connected no matter where you are. To learn more, visit bekonix.com.



LIVE TESTING

When I build any kind of robot, I prefer to be in manual control until I'm 100% certain the components are working comfortably within their operating limits. During final assembly we use a simple radio receiver and controller to test each motor manually and operate the various movements "live." This gives you time to stop a motion that could damage something if it's not working correctly. Test each function individually before moving onto show programming.

AUDIO

Bruce's accompanying audio track was stored and played separately from the animatronic, via our client's pre-existing show control system. Though the Bekonix board can store and output audio, we opted to use the client's setup instead, for easier integration with elements made by other vendors. Our animation was timed to match their track, with a DMX signal to the Bekonix Connect board signaling the start of the show.

It's important to remember that any animatronic will make audible motor noise; however, generally the show audio will provide more than enough cover. The goal is a sensory trick, in which the viewer perceives the show sound as coming from the character itself, even if the speakers need to be placed in a different location.

The final audio track should always be finished before animating the character, so that all motions can be motivated by specific sound cues, and specifically timed to the show.

THINK LIKE A PUPPETEER

When it comes time to actually animate the character performance, think like a puppeteer.

Bekonix

Often we will shoot reference footage with a simple hand puppet (or even our own faces) so that we have specific motions to mimic in the animation process. This is especially important when manually animating using numerical values for motor input, rather than recording a live RC performance for playback.

Bekonix Designer specifically lets you drag and drop motor control in a timeline editor, and adjust the PWM values as needed, with transitions, fades, and other effects available at your disposal. After you determine the desired PWM range and set it accordingly (this will be different for every servo brand), the performance can be animated one element at a time. This always takes some trial and error when you first get a new project built and running.

SKINNING

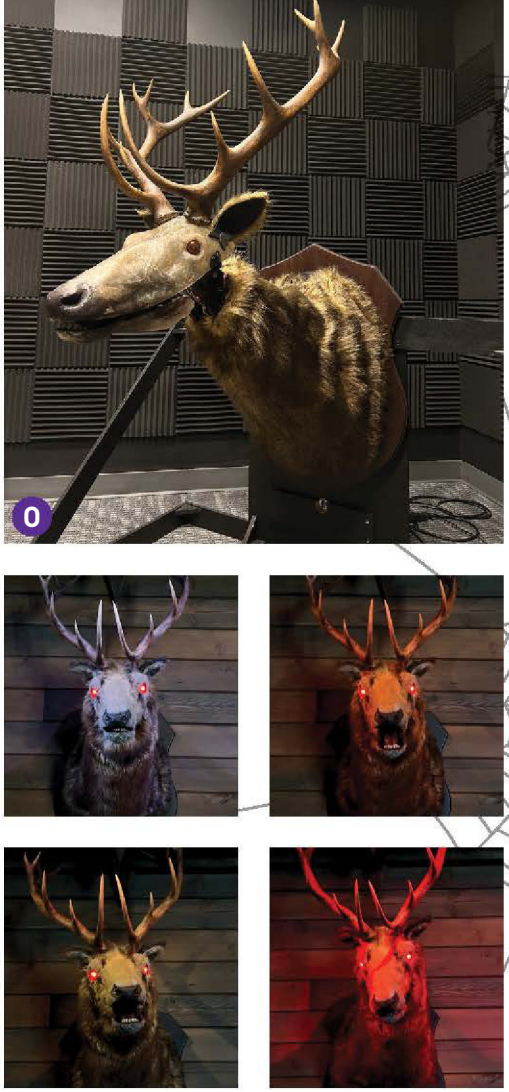
Obviously the outward appearance of a character is one of the most important elements to its believability. Realistic fur and wildlife sculpture are artforms of their own, but here are a few tips. Most fabric does not stretch, and your animatronic's final covering must not inhibit its movement. Include relief areas and extra material where you can, to ensure the full range of motion and not exert undue pressure on the motors or internal structure.

Bruce is skinned with several types of synthetic fabric-backed fur, and padded with upholstery foam to define muscle shapes (Figure 0). The same fur on his body is applied to his face, and then trimmed with heavy-duty electric shears, like the kind a dog groomer might use.

DIALING IT IN

For an installation animatronic like Bruce, the show animation should always be finished *in situ* with the complete show elements (light, sound, atmospheric effects, etc.). While bench testing before installation is essential, there are nuances that may not be observable outside of the final show setting.

With Bekonix, live motor control editing is relatively simple. The Bluetooth capabilities of the Connect Controller board allow you to update show animation wirelessly, and rehearse playback on site, using their mobile app. Minor



adjustments in motor speed and timing often make all the difference.

After assembly in Denver, Colorado, we delivered Bruce to the site and installed and perfected his animation over a two-day period.

Bruce is still doing his thing at Slashers Axe Throwing & Ales, so if you're in the area or planning a visit, make sure you give them a visit. The team at Slashers has put together an amazing experience for classic horror fans, and we are honored to have helped create some magic in their space.

See Bruce come (un)alive in the video *Building Bruce: Animatronic Taxidermy* at makezine.com/go/animatronic-deer.

Animatronic SINGING SPOOKS

PRINT, BUILD, AND **ANIMATE YOUR OWN MUSICAL GHOSTS** USING BOTTANGO'S FREE ANIMATRONIC SOFTWARE

Written and photographed by Evan McMahon



Starting to learn animatronics as an art form can be really intimidating. Programming, mechatronic design, electrical engineering … the list of required skills goes on and on. And to be honest, I think that's no fun! Animatronics should be an art form available to everyone.

To make animatronics more accessible, I've been developing Bottango (bottango.com) for over five years. Bottango is free animatronic animation software that's been used for years by beginners on up to industry professionals to create dynamic animatronic performances.

In Bottango, you use industry-standard animation workflows for animating digital characters, like you would in 3D movies and games, and apply those techniques to real-world animatronics. Instead of creating animations in hard-to-visualize code, you use keyframes along a timeline to make movements of a 3D simulation of your robotic invention. You can get as fine-tuned as editing the interpolation of movements using an industry-standard animation graph editor, or even do live recording of puppeteering on a gamepad which automatically converts to editable keyframes.

Bottango works on any Arduino-compatible microcontroller and easily produces lifelike and creative movements of your own robot designs, using open source hardware you probably already have in your closet.

To make something fun and simple for Halloween, I was inspired by Louie Zong's viral *Ghost Choir* video (youtu.be/kXF3VYYa5TI). Once you finish building these characters and mechanisms, you'll use a premade Bottango project and animation to perform the *Ghost Choir* song right out the gate. Big thanks to Louie Zong for giving permission to use his song for this build. You can see a video of the final result at the project page, bottango.com/singingghosts.

And after it's all built, you can then use Bottango to bring in your own audio and create your own animations for the characters.

DESIGNED TO BE EASY

For this project, I wanted to design a simple animatronic that anyone new to the art form could put together. Each ghost can float up and down, look/bend up and down, and look/turn

Adobe Stock-pixaroma & Vjom, Louie Zong

TIME REQUIRED: 2–3 Hours + Printing

DIFFICULTY: Moderate

COST: $300

MATERIALS:

- **Servomotors, standard size (6)** MG99GR or better quality
- **Metal servo horns (6)** with M3 bolt holes, such as ShareGoo Metal 25T
- **Servo extension cables (6)** at least 300mm
- **Arduino compatible microcontroller** Arduino Uno recommended
- **Servo power source** such as Bottango Servo Shield, bottango.com/products/bottango-servo-shield (recommended), or Servo City 3108-2827-0801
- **Power supply, 5V 5A** compatible with your servo power source. If using Bottango Servo Shield, get a barrel plug, 5.5mm outer sleeve, center positive.
- **Socket head bolts, M3: 12mm (50) and 8mm (20)**
- **Hex nuts, M3 (20)**
- **Threaded rods, M3×40mm (4)**
- **Rod end ball joints, M3 (8)**
- **PLA filament: black, and glow-in-the-dark**

TOOLS:

- **Hex driver or Allen key, 2.5mm** for socket head bolts
- **3D printer with steel nozzle** for printing glow-in-the-dark filament
- **Computer (Mac, Windows, or Linux) with software:**
  - **Bottango** free at bottango.com
  - **Arduino IDE** free at arduino.cc/downloads



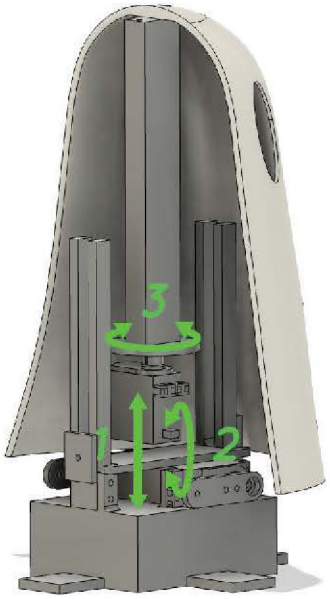
EVAN MCMAHON is a lifelong theme park and animatronic lover based in Seattle, who is translating 20 years of game development experience into tools that make creativity in animatronics and robotics more accessible and fun.



***Ghost Choir* video by Louie Zong**

left and right (Figure A). Though the characters and mechanisms are simple, by using powerful animation tools, you can get a lot of emotionality in the animatronic performance.

In order to keep this build easy, the design has some drawbacks. I wanted it to be entirely 3D printed, without hard-to-source hardware like bearings, and take under an hour to assemble. With those considerations, understand that the movement will be a bit shaky and noisy, as the plastic reverberates from the servos and doesn't have additional hardware to "shore it up." Better quality and quieter servos can help and, as with all animatronics, you will cover up some of the noise with your own soundtrack playing over speakers.



A



B

BUILD YOUR SINGING ANIMATRONIC GHOSTS

You can get the 3D model files for printing, recommendations of specific materials and hardware, and more details for this build at the project page, bottango.com/singingghosts. If you'd like to discuss the build and learn more about using Bottango, join the Bottango Discord server at (bottango.com/discord).

1. SET UP YOUR ARDUINO

To start, we need to get a microcontroller and power circuit ready to go for our servos. The easiest and most accessible microcontroller option is a tried and true Arduino Uno.

When you download Bottango, you'll find a *BottangoArduinoDriver* folder. Using the *BottangoArduinoDriver.ino* Arduino sketch in that folder (Figure B), you'll have everything you need already coded for you. Install the driver onto your Arduino using the Arduino IDE, and it will be ready to communicate with the Bottango desktop app.

You can use most any Arduino-compatible microcontroller with Bottango, as long as it can reliably move servos. For less common microcontrollers, you may have to make a few minor changes to the driver, but it's open source!

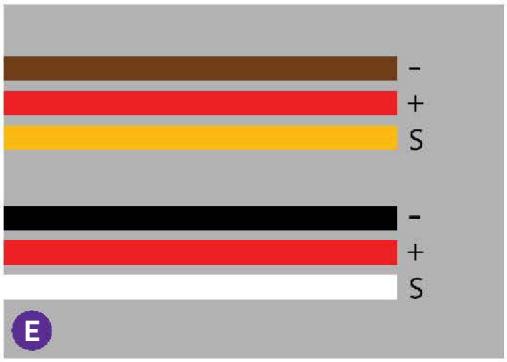


C


D

2. THE POWER OF SERVOS COMPELS YOU

To power the servos, I'm using Bottango's Servo Shield (Figure C) and a basic 5V 5A power supply. It plugs straight into the Arduino Uno and takes





a normal power supply barrel jack. That's it! I designed it to be the easiest way to power servos with an Arduino.

Check the project page for some alternatives as well. You can easily use the 8-channel Servo City power distribution board. A popular option, though not recommended for this project, is the Adafruit 16-channel PCA driver. To use it, you'll need to make a few minor (and documented) changes to the open source Bottango driver, as well as to the provided ghost project file. Note that some lower-cost versions of that board may not handle higher-current applications, and the extra I²C communication required to use that board can add some latency to the animations.

Plug the Bottango Servo Shield (if you're using it) into the Arduino (Figure D). Now the headers on the shield are connected to the pins on your Arduino. A servo plugged into the header 2 on the shield will be connected to pin 2 on your Arduino.

The headers are labeled to match standard servo cables (Figure E):

+ will be the red wire on your servo
– will be the black (or brown) wire on your servo
S will be the white (or orange) wire on your servo.

3. PRINT, PRINT, PRINT

Both ghosts have the same mechanisms, so you'll print everything twice, except the two ghost shells; you'll print one of each of these. I printed the mechanisms in black PLA so they're less visible, and the ghosts in glow-in-the dark PLA (Figure F). Glow filament is very abrasive, so you need a steel nozzle that's made for abrasive materials or you risk damaging your printer.

Heads up that these are some big ghosts, so cozy up for a long print! The wider ghost is 228mmL × 223mmW × 185mmH. The taller ghost is 202mmL × 207mmW × 246mmH. If you need to shrink your ghosts slightly to fit on your printer, you may be able to; there's some clearance between the mechanisms and the shell. Be prepared, if you do scale them, to drill or adjust the top mounting holes to get back in alignment with the mechanisms. I printed all my parts and ghosts on a Bambu Lab P1S.

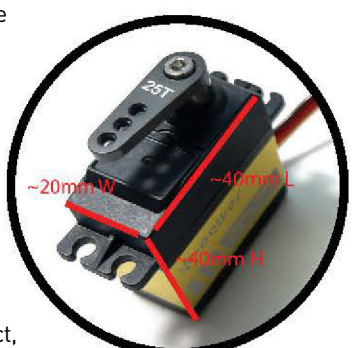
The parts were designed for 3D printing. Everything in my build was printed without supports, but depending on how well your printer can handle bridging, your large ghost shells may need some support under the tops.

Print the parts named *Side1*, *Side2*, *SquareNut1*, and *SquareNut2* on a smooth surface plate. You want one side of each of these parts to be as smooth as possible, as they'll be sliding against each other.

The holes in the printed pieces have been sized a little tight to allow a bolt to self-tap while driving into place, and stay in place.

4. PREP THE SERVOS

For selecting servos, we aren't moving anything too heavy here, so you don't need enormous torque. Just make sure they're "standard size" servos (Figure G). The better servo you buy, the smoother movement and quieter sound you should expect, and the longer you can plan for this build to keep working.





H

Personally, I hate the plastic horns that come with servos; they're almost impossible to work with. Instead, we'll use nice metal horns that have easy-to-use, threaded M3 bolt holes (Figure H) at 12mm, 16mm, and 20mm. These are generic pieces that multiple manufacturers make; if you search Amazon for "metal servo horn" you'll find a few different brands that look just like this.

The print files are designed with this specific metal horn in mind, but the STEP files should let you change things up if you need to move the mounting holes on the project around. Having threaded mounting holes on the horns is a must!

Make sure each servo is centered before you put the horns on. It's important that your servos are in a predictable state when at their "home" resting position. On the project page, I've included a simple Arduino sketch for centering servos. Upload the *ServoCenter.ino* sketch onto your microcontroller, and connect power to the servo shield. Then if you put the servo on pin 3, you'll test if it can move correctly; it should sweep back and forth. When you put the servo on pin 5, it'll center the servo. Always put the horn on while the servo is centered, ideally with the servo connected to pin 5 with this test sketch running.

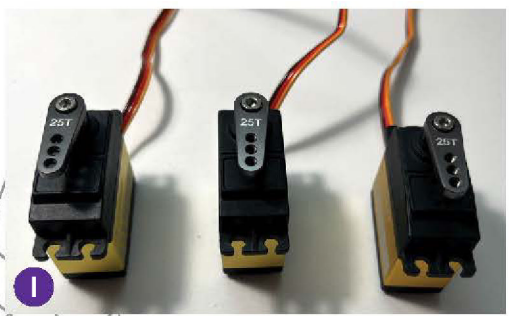
For all six servos, attach the horn pointed back in toward the center of the servo (Figure I). I like to use some of the M3 8mm bolts to attach the horn, rather than the screws that come with the servos.

Add the rubber isolator grommets that came with your servos to the servo mounting holes (Figure J). These grommets help adjust for differences in exact servo dimensions between models, as well as dampening vibrations. We'll skip the metal eyelet inserts; they're more for the world of RC, and not needed here.

5. BUILD THE BASE

For the following assembly steps, you'll be doing everything twice, once for each ghost. Use 12mm M3 bolts unless called out to use an 8mm bolt.

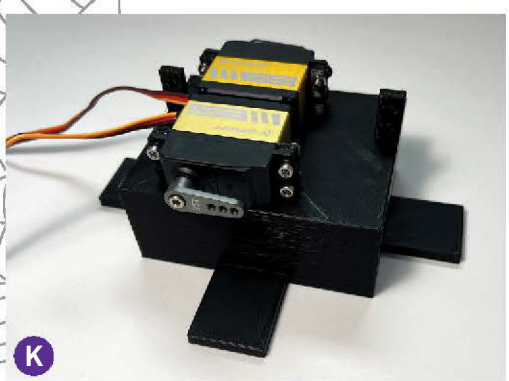
Mount two servos onto the base. The cables

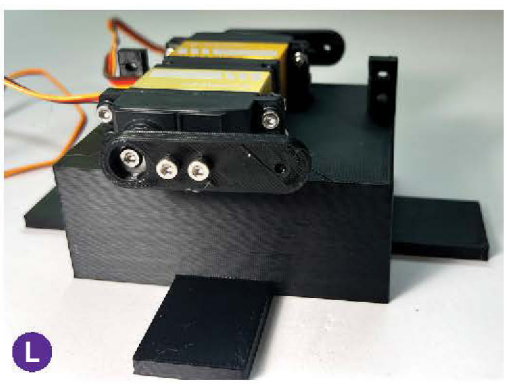


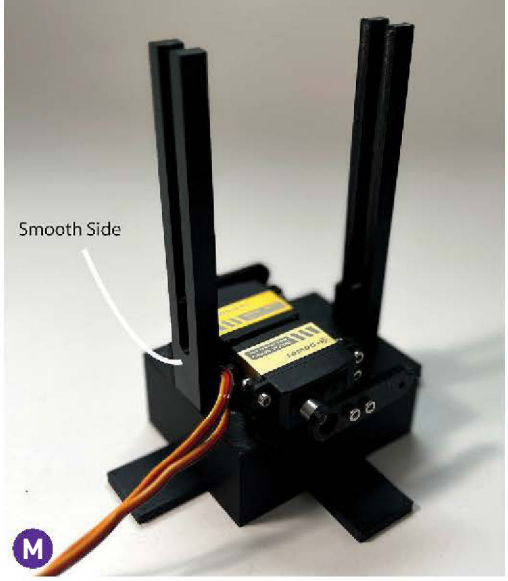
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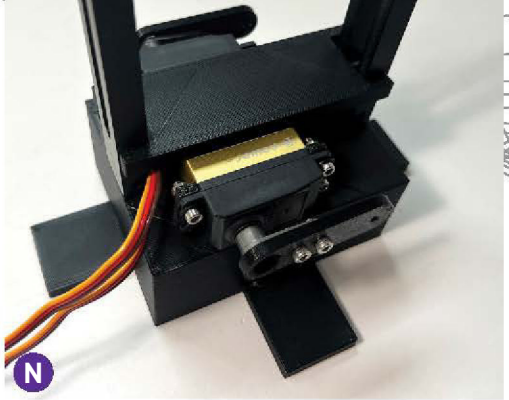


J


K


L



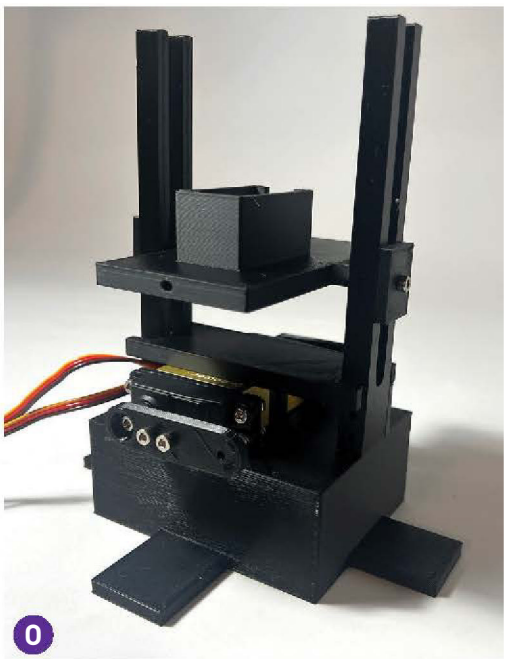


should be inside, and leading the same direction on both servos. You want the horns pointing in the same direction as well (Figure K). Use hex nuts to secure the servos in place.

Add the printed horn extensions to both servos, again pointing in the same direction (Figure L). Use 8mm bolts to attach these; 12mm bolts will go too far.

Attach the two side pieces to the base. You want the smoothest printed face of each one facing outward (Figure M).

Finally, slide the tensioner piece from the top down (Figure N). This helps keep the side pieces straight so there isn't extra play at the top.

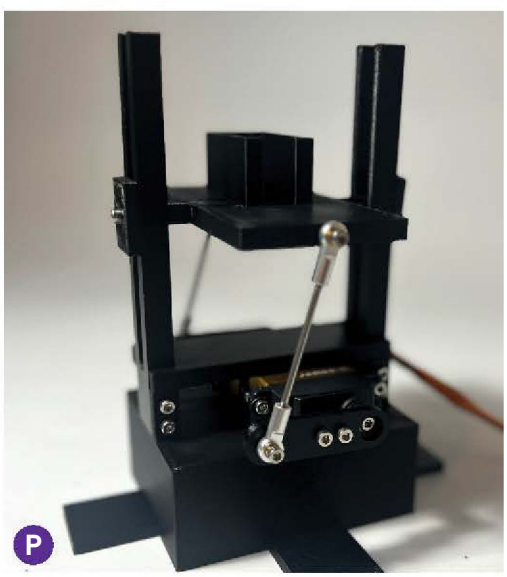


6. SET UP THE MAIN DECK

Attach the two square nuts to the main deck, with their smooth printed side facing inward. Then slide the main deck down the two side pieces until it rests on top of the tensioner (Figure O). As the two base servos move together, they'll move the base up and down, and as they change their relative movement, the base will rotate.

Try moving the main deck up and down. If it feels too tight at the bottom of the range of movement, you can adjust the tension by loosening the square nuts. Find the right balance of tension so that it doesn't have too much play at the top, while not being too tight at the bottom.

Take two threaded rods and attach ball joints to both ends. Bolt one ball joint to the end of a horn extension, using a hex nut to hold it in place, and bolt its opposite ball joint to one side of the main base. Repeat on the other side (Figure P).




Q


R


S


T

7. ASSEMBLE THE ROTATION SERVO

Put aside what you've built so far, and move to the third servo and ghost body.

Attach the long ghost stand piece to the printed rotation horn (Figure Q).

Attach the rotation horn to the metal horn of the third servo. Be sure to use 8mm bolts here again (Figure R).

Take a printed ghost shell, and attach it into the top of the ghost stand as shown in Figure S, with the servo's cable leading toward the back of the ghost. This may be tricky, as you'll be working a bit blind, and if your printer didn't get the bridging great, it may be a little messy around this part. Stick with it, though; this is probably the hardest step!

Finally, slot the ghost body and rotation servo into the main deck. You won't need to do any blind bolting here; the large slot on the deck should hold everything in place. Make sure the ghost is facing forward, and oriented so the servo cables on the stand are facing its back, and the servo cables on the base are on its right (your left) (Figure T).

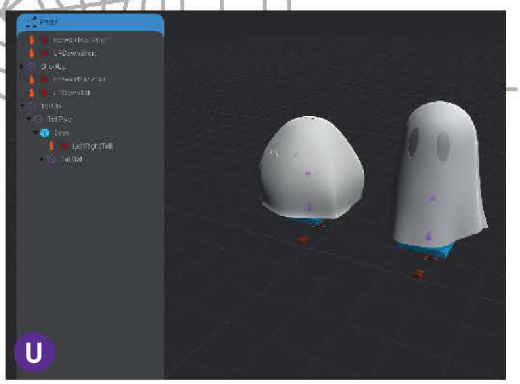
I cut out some black sticker paper to darken the eyes. You could do the same, or use markers or paint, or leave them as printed with an inserted look.

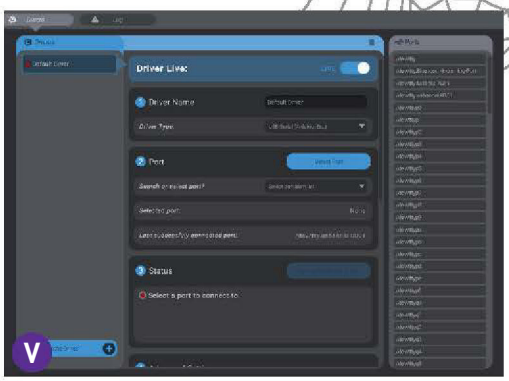
8. WIRE IT UP

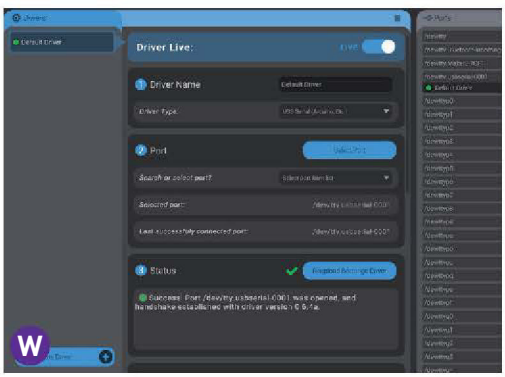
That's it for the assembly of the mechanisms! Add servo extensions to all servos, and then connect the servos to the headers on the servo shield as follows:

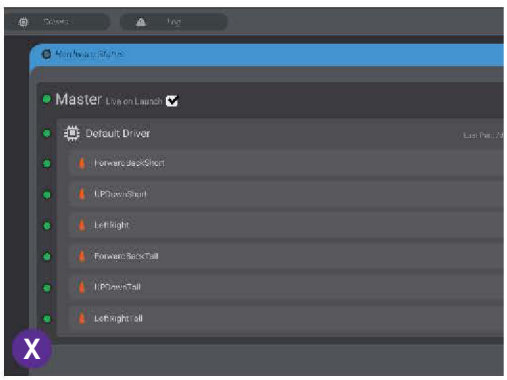
- Tall ghost front base servo (2)
- Tall ghost back base servo (3)
- Tall ghost rotation servo (4)
- Short ghost front base servo (5)
- Short ghost back base servo (6)
- Short ghost rotation servo (7)

With power into the servo shield, and the Arduino set up with the Bottango driver and connected to your computer, you're ready to bring these ghosts to life ... well ... as much life as a ghost can have.









9. PREP FOR LAUNCH

Along with the 3D model files, in the downloads for this build there's a ready-made Bottango project file with an animation and song. It was made with the same tools that animatronic builders use to set up their own custom builds in Bottango. Make sure you've downloaded the latest version of Bottango, then launch it and open the project file.

With the project open you should see the ghosts, and the Build tab selected at the top (Figure U). This is where you set up the project and simulate your real-world animatronic, but we've done all that work for you.

First, you'll need to connect to the Arduino. Select the Hardware tab at the top of the screen, and then the Drivers sub-menu (Figure V).

We need to tell the project which serial port your Arduino is on. Press the Select Port button, and then select the port from the right side of the screen. On Windows it will be something like **`COM3`**, though the exact number may change. On Mac it'll usually start with **`TTY.USBSerial`** or something similar.

If you're successfully connected, you should see a "green light" in the status section of this menu (Figure W). If not, feel free to dig into the Bottango documentation, or visit the Bottango Discord server for help.

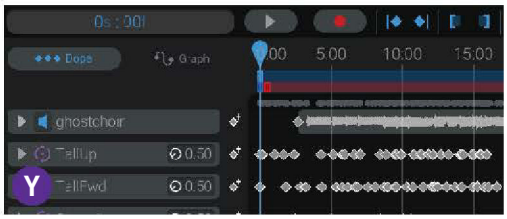
We need to "turn on" each of the six servos now; they're off by default in Bottango. Move over to the Status submenu, and click the on/off switch on each of the six servos to turn them on (Figure X). As you turn them on, if everything is powered correctly, the servos may jump back to home.

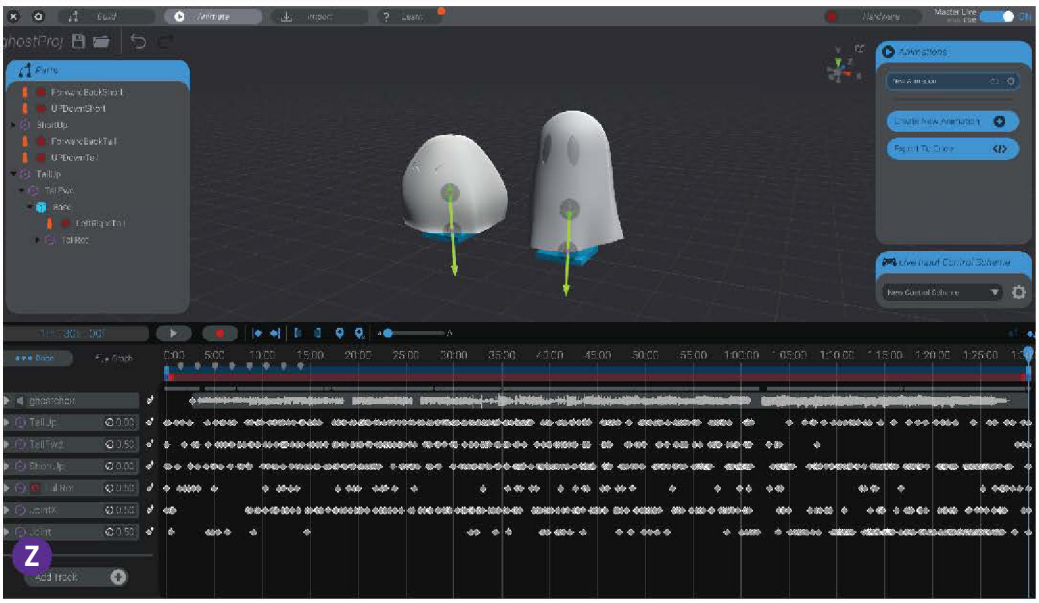


WE ARE "GO" FOR GHOSTS!

Head back over to the Animate tab, and click the Play button in the bottom of the animation view (Figure Y). Sit back and enjoy the show!

A big thanks again to Louie Zong for letting me use his song in this build!





CREATE YOUR OWN GHOSTLY PERFORMANCE

These aren't just one-trick ghosts. You can bring in your own audio files (or videos) and animate these singing ghosts yourself.

Because the project file has been set up with the 3D models of the ghosts and digital twins of the mechanisms, as you animate your characters on the screen, you'll see the exact same performance, one to one, between the digital copy and the real-world animatronics.

You can animate more than just servos too! You can bring your creativity to life using stepper motors, lights, relays, Dynamixel actuators — even add your own custom hardware into Bottango.

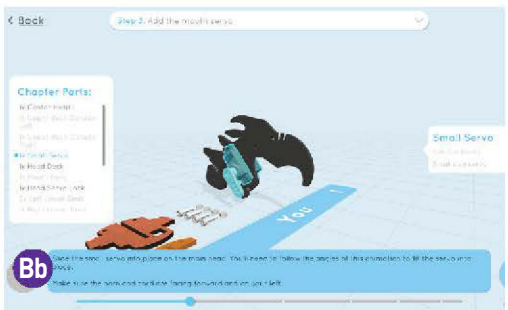
Animations in Bottango are created using keyframes, along a timeline, interpolating from one key pose of the ghosts to the next (Figure Z). These are the same kinds of tools that the pros use to make digital animations. You can bring in reference videos and animate your characters right along with a real-world performance. Or record a video of yourself doing your own spooky dance, import it into the project, and then use that as a reference for an animation. Or hook up a game controller to live-puppeteer the characters, and it will be recorded and translated back to editable keyframes.

When you download Bottango, you'll find a thorough, 300-page documentation PDF that teaches you all the ways to use and animate with Bottango. The Bottango Discord community is a great place to learn and ask questions.

READY-TO-BUILD ANIMATRONIC KITS

Maybe you had so much fun building these ghosts that you want more characters. Or it's a little intimidating to try and source all these parts and know if you've got the right pieces. Bottango, besides making awesome free software, has "everything in the box" animatronic kits available (Figure Aa).

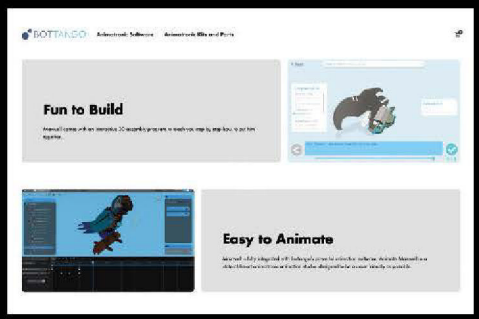




Bottango's kits are a really easy and fun way to explore the art of animatronics, no prior experience or special tools needed. You get all the parts, hardware, circuits, tools, and servos you need to build a fully functional character, plus a fun 3D assembly program to show you how to build (Figure Bb), and special optimized animation tools to animate the character.

Animatronic Kit: Maxwell

$349 bottango.com/kits



Maxwell isn't just another robot kit; it's about opening doors to the animatronics universe, making it a friendly, approachable journey for all, from eager beginners to seasoned tinkerers.

Opening Maxwell's box is fun and well organized, each component tightly packed, the laser-cut pieces individually wrapped. The 3D instruction manual guides users through assembly and the wonders of mechanics and electronics with a gentle hand. Maxwell's features are thoughtful and innovative: Its lifelike motions include mouth movement with spoken word and flapping wings to enunciate emotions, and its programming interface Bottango is more welcoming than daunting, based on recording movements and automatically translating them to code. It's not cheap, but it's built with care and designed to endure for lots of exploration.

Bringing Maxwell to life is a process filled with small victories and learning moments. It's designed to challenge but not frustrate, ensuring that every step forward is a step gained in knowledge and confidence. Maxwell moves in many different axes and its responsiveness feels almost magical, as though reacting not just to inputs but to the intention behind them. It's here that Maxwell shines, demonstrating both the capabilities of its design and the potential of its user to create, adapt, and innovate.

—Isaac Honikman, age 15

Simple ANIMATRONIC EYES

Written and photographed by Will Cogley



BUILD A **REALISTIC EYE MECHANISM** FOR LIVE JOYSTICK CONTROL OR AUTOMATED PROJECTS!

Animatronics, once relegated to the realms of theme parks and big-budget movie sets, are experiencing a renaissance in our DIY culture. Perhaps it's childhood nostalgia, certain horror-themed video game franchises, or the desire to explore the intersection of technology and artistry. Whatever the reason, there's excitement surrounding the creation of animatronic marvels. And amidst this wave of enthusiasm, there's never been a better time to embark on your own animatronic journey! In this project you'll build a realistic eye mechanism you can control with a joystick — and integrate into any project you like!

To start with, my code will allow you to look left and right, up and down. As the gaze moves up or down, I've programmed the eyelids to follow them subtly which adds a surprising amount of realism. Using a button, you can also trigger a rapid blink. Since we're using a programmable Arduino you could also write your own code to move the eyes autonomously or even integrate them into a larger animatronics project!

1. PRINTING

With a healthy printer, printing should be no issue without supports. There are some thin sections and snap-fits so you might benefit from printing with a stronger material like ASA or PETG, but I used PLA and had no trouble at all. 0.2mm layer height is a good guideline.

Download the files for printing from makezine.com/go/animatronic-eyes. Note that I have a few different options for the eyes — a blank, round version, a version with an iris and pupil cutout, and a highly realistic version you can build as a whole separate project you can find at makezine.com/go/universal-eye-casting! I designed them all to use a common interface, so they attach with a snap-fit to my "eye adaptors" as they're called in the download pack. But you can use anything else so long as it's 32mm diameter or less and can fit the eye adaptor!

You may want to do some sanding on the inside of the eyelids since the 3D printer would've been printing an overhang in this area and the gap between the lids and eyeballs is quite small. The parts are designed to print such that some holes are undersized enough to be directly screwed into, whereas others are oversized enough so the screw will pass through and allow for rotation. If your printer's not the most accurate, you can use a drill to adjust any hole sizes which are too tight for smooth movement.

TIME REQUIRED: 1 Day

DIFFICULTY: Easy/Moderate

COST: $50

MATERIALS:

- **3D printer filament** PLA is fine, but use a good brand because some parts are quite small and fragile. ABS is good for making realistic eyes but not necessary.
- **Micro servos, SG90 (6)** Amazon B0B68NTZ6H
- **Screws, various M2 and M3** OK to use different lengths/head types. Amazon B098KXZNY6
- **Arduino microcontroller** Uno, Nano, Mega, or similar
- **Servo Driver Board, 16-Channel** Amazon B00EIB0U7A
- **Power supply** around 5V, 4A. Amazon B0CP7G8Z7R
- **Corresponding female DC power jack** Amazon B09H5L3KN5
- **Joystick, 2-axis** Amazon B00P7QBGD2
- **Potentiometer (optional)** Amazon B019I13X5K
- **Momentary pushbutton** aka push-to-make switch. Some joysticks have this built in, but it's easier to control when separate. Amazon B01CGMP9GY
- **Resistor, 10kΩ** Amazon B01F06T56I
- **Breadboard jumper wires** for the Arduino. Amazon B01EV70C78
- **Sandpaper** around 240 grit

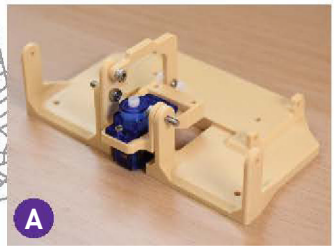
TOOLS:

- **3D printer**
- **Pin vise hand drill (optional)** useful for adjusting hole sizes if using an older/less capable 3D printer. Amazon B098CF3VMM
- **Screwdriver(s)** to match your screws

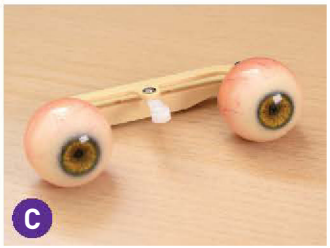


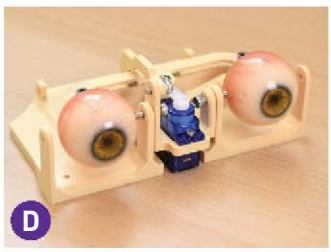
WILL COGLEY is a London-based engineer fusing mechanics, electronics, and artistic creativity to make top-notch robotics and animatronics. Inspired by biology, he builds robots that mimic the natural world and shows you how on his YouTube channel!

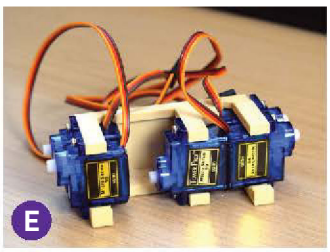
Adobe Stock-pixaroma & Vjom













2. ASSEMBLY

Connect the two bases with 10mm or 12mm M3 bolts. This pivot point is for the y-axis of the eye motion and the eyelids.

Place the servo in position and screw it in with some 4mm or 6mm M2 screws (Figure A). This serves as the actuator for the x-axis motion.

Attach the y-axis arm to the sub-base with a 4/5/6mm M3 screw, and attach a servo horn on the third hole from the center using a 4mm or 6mm M2 screw, as shown in Figure A. Check to make sure the orientation of everything is right.

Start building the x-axis assembly (Figure B) by screwing the forks into the eye-adaptors with 4/5/6mm M3 bolts. The fork holes should be oversized so the screws bite into the adaptor. One goes in on a funny angle but you should be able to get it in.

Attach the three-point connector to the top of the forks; the M3 screw will bite into the undersized hole in the fork component. Also attach a servo arm on the final hole to the center of the three-point connector using a 5mm M3 bolt as in Figure B (the hole on the servo arm will likely need to be drilled to 2.5mm–2.8mm to accept the screw). I'd recommend manipulating the assembly regularly as you build it up, to make sure it all moves OK without friction.

Attach the eye center-link to the eye adaptors with an 8mm M3 screw, making sure the flat surface of the center-link is facing up and the sloping section is facing down. You can also plug in the eyes at this stage (Figure C).

Screw all this to the center of the sub-base with two 12mm M3 bolts (Figure D).

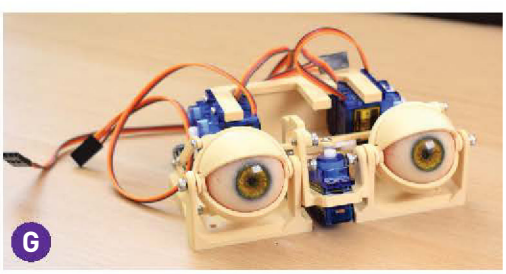
Load up the servo block with five TowerPro SG90 servos, in the correct orientation shown in Figure E. Attach it to the base with four M3×10mm bolts.

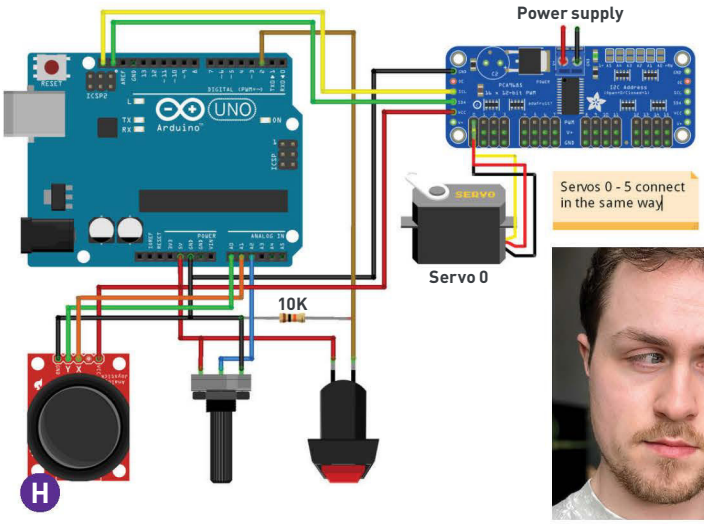
Work out which eyelid is which using Figure F. Connect the relevant connector with a 4mm or 6mm M2 screw, and attach a servo arm to the other end, using the last hole in the servo horn — you may need to drill this to 1.5mm–1.8mm.

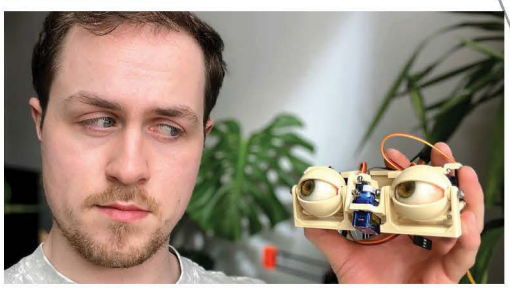
Attach the eyelids to the base (Figure G), but don't worry about connecting any servo horns yet.

3. WIRING, CODE, AND FINISHING UP

Upload the code to the Arduino, and wire everything up (Figure H). Check the Adafruit guide (makezine.com/go/16ch-servo-guide) if you need help setting up the servo driver board, but all you should need to do is download the Adafruit Servo Driver Arduino library. All servos should now be powered and in their neutral







position, so use this opportunity to link up all the servo arms to the servos, with the eyes facing straight forward in a neutral position. You can just plug them in while powered up, then disconnect the power to screw them in properly. The y-axis servo arm is in an awkward position to accept a screw, but I found that it held fine without a screw anyway. If yours doesn't, it may be helpful to remove one of the eyelid servos to screw it in. I'd recommend testing the motion with your joystick at this stage to make sure there are no issues.

For the eyelids, it's best if you attach the arms of the servo while they're in the blinking position so you can line up all four of them in the center. Do this by holding down the blink switch or creating a short circuit over it. Once all the servo arms are in position, pop a screw in to keep them secure.

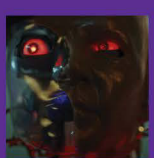
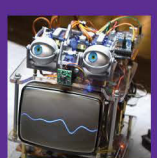
4. OPERATION AND INTEGRATION

Your model should be complete! Now you can put eyes in your pumpkin, T-800, or animatronic pizza bear. Using the joystick, the eyes will follow the direction you point in, and the eyelids will move very slightly to match the position of the eyes. Pressing the button will make the eyelids snap to the center, so by pressing it quickly you'll get a fast and realistic blink. The potentiometer is there to allow you to adjust how open/closed the eyelids are at rest, so you can turn it down to get a sleepy look or turn it up to look more alert.

If you want to build on this project and add extra animatronic parts, there are still plenty of pins on the Arduino and driver board to allow you to add to it. And if you already have a larger animatronic project you'd like to integrate these eyes into, you can simply swap the inputs from the joystick, potentiometer, and button for signal cables from your larger project's controller. You can control the direction with an analog signal through pins A0/A1, and the openness from A2, and send a high/low digital signal for blink.

Eyeball These Builds From the Community!

Here's a look at some of my favorite animatronic eyeball builds from makers around the world!

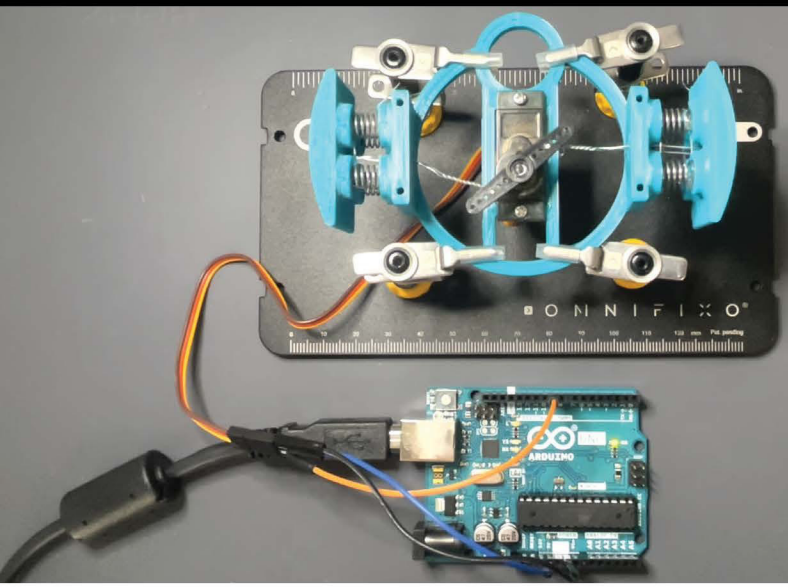

Anatomorphex/Prettybird/SZA, Thomas Burns, Seraphim2945

- **Robert Devine/Anatomorphex:** used in the video for the Grammy-award winning *Snooze* by SZA! youtu.be/LDY_XyxBu8A
- **Thomas Burns:** integrated with an Amazon Echo Dot to make a personal assistant. makezine.com/go/alexa-personality
- **Seraphim2945:** built the eyes into an entire open-source humanoid robot. makezine.com/go/animatronic-head

The Breath OF LIFE

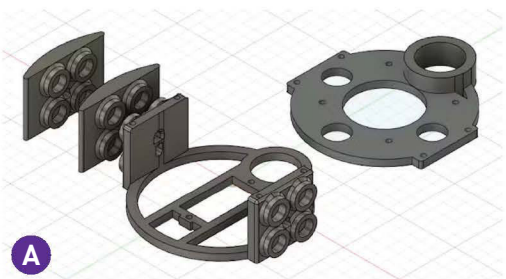
SIMULATE **REALISTIC BREATHING** INSIDE YOUR ANIMATRONIC CREATURES

Written and photographed by Katherine Connell





KATHERINE "SMALLS" CONNELL is a self-taught maker based in Los Angeles, and the creator of Sprite Lights wearable LED tattoos. Insatiably curious, she has learned 3D printing, CAD drawing, prosthetic making, sewing, watercolor painting, costuming, circuit design, PCB creation, and much more. @smallswonderworks





I'm building a companion bot with head motions but I wanted to add movement to the body as well, to help it feel more lifelike. I decided on a breathing motion and designed this 3D printable gadget that uses springs and a MG90S servo. It's controlled by an Arduino running a ***servo easing*** program to vary the rate that the servo moves, for lifelike motion. See it breathe at youtu.be/Np_GQmlyw3I, then grab the code and my files for 3D printing at hackster.io/TheSmallWonder/f7e27e.

1. PRINT THE ENCLOSURE

I printed all parts (Figure A) with four outer shells and 20% infill to prevent it from bending.

2. SET SERVO TO NEUTRAL

Plug your servo into the Arduino and upload the *servo_neutral.ino* sketch. This sets your servo to the 90° neutral position. Unplug the servo.

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3. GLUE THE SPRINGS

Hot-glue the springs into their holes on the inner piece, then into the outer rib plates (Figure B).

4. ATTACH SERVO HORN AND WIRES

On the long symmetrical horn that came with your servo, screw a tiny M1.2 screw into the third hole on the inside of each arm. Then attach the horn to your servo.

Cut a length of 24 gauge wire long enough to be folded in half and reach from the tiny screw to the very outer edge of your assembly. Twist this wire around the tiny screw on the server horn, making sure it can't slip off the head but is still be loose enough to rotate freely around the screw. Repeat on the other side (Figure C).

5. MOUNT SERVO AND ATTACH WIRES TO RIB PLATES

Mount the servo to the inner assembly using M2×6mm screws. Thread the wires through the two holes on the inner assembly and through the rib plate holes. Making sure not to compress the springs, twist the wires tightly and then tuck the excess inside the rib plate hole (Figure D).

6. ATTACH THE FACEPLATE

Attach the top with M2×10mm screws (Figure E).

7. UPLOAD THE BREATHING SKETCH

Plug the servo into the Arduino, then upload the *servo_easing_breathing.ino* sketch. You can adjust the breathing speed by increasing or decreasing the second number, the ***blocking value***, here:

```
breathe.easeTo(145, 55); //angle moved to and blocking aka time for arrival to the angle, the lower the blocking number the slower the servo moves
breathe.easeTo(90, 55); //sets servo back to neutral 90 degree angle
```

To prevent the servos overheating and melting things, we give them a small break during each breathing cycle by including the **`breathe.attach();`** and **`breathe.detach();`** commands in the **`void`** loops.

Check out more types of easing functions at easings.net!

TIME REQUIRED: 6 Hours

DIFFICULTY: Easy/Moderate

COST: $50–$65

MATERIALS:

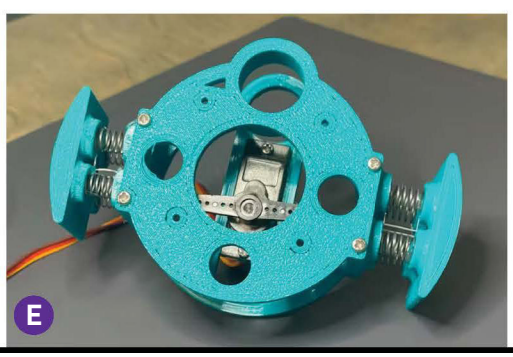
- **Servomotor, MG90S**
- **Arduino microcontroller board** Uno or similar
- **Machine screws: M1.2×4mm (2), M2×6mm (2), and M2×10mm (4)**
- **Compression springs, 6mm×15mm, 2.3lb (8)** Amazon B0BBQL2SN3
- **Craft wire, 24 gauge**
- **Jumper wire**
- **Hot glue**

TOOLS:

- **3D printer**
- **Hot glue gun**
- **Screwdriver and pliers**







Projection Mapping



KAT BLACK and **JASPER COOK** met at Art School in Perth, Australia in 2003 and have been working as creative duo VJzoo ever since then.

Written and photographed by VJzoo
Illustrations by Midjourney
Films from Archive.org



For Halloween or any time, here's how to cast still and moving images using buildings as your screen

Want to be the envy of your neighbors this Halloween? If you have access to a projector, and a laptop with a GPU and sufficient specs, you can create a spooky display that's sure to impress all your candy-seeking visitors — and it won't cost you a cent.

Our small team at VJzoo have been projecting since 2003 and can help you to make the most out of whatever projector you can get ahold of. We used to do a lot of street projection with quite small projectors, so we've got tips and tricks to help you accomplish an effective display on a minimal budget. For starters:

- **Simple, bold content —** Big, bright designs will show up best. Subtle work, like photography and detailed illustration, can be lost on a wall unless it's a very plain, single-colored wall.
- **Black background —** Break up the edge of your frame with an irregular black background to get away from the usual 4:3 or 16:9 rectangular shape. This makes it seem less like "shoddy screen" and more like "content interacting with wall surface." Black does not project, so black areas will be the color of the wall. Avoid white backgrounds, as they will just light the surface of your building.
- **"Inverted silhouette" content** shows up very well, even with quite a bit of ambient light.
- **DLP projectors** are more suitable than LCD — more bang for your buck, higher contrast, brighter colors, and you won't really notice the DLP's "rainbow effect" like you do on a screen. Laser projectors are even higher contrast, if you have access to one. But basically, use what you can get.
- **Avoid ambient light —** Try to get nearby lights turned off, or mask them with foil. Peripheral light is your biggest obstacle.
- **Play safe —** Don't play fast-moving or otherwise distracting content near traffic.
- **Clean power —** Mains power is best if you can get it. That's always our first choice. If you need to use a generator, make sure it's a "sine wave" generator, or else use a sine wave inverter with a normal generator, deep-cycle battery, or car battery (with the car running). Hot/spiked power or low/browned-out power can destroy a projector instantly.
- **Test, test, test —** The only way you can really tell how projection will look on a particular wall is to try it. Especially on surfaces like windows, it's difficult to predict what will show up. So give it a go!

TIME REQUIRED: A Weekend

DIFFICULTY: Moderate

COST: Free

TOOLS:

- **Laptop computer with GPU, Windows or Mac, with software:**
  - **TouchDesigner Non-Commercial** from derivative.ca
  - **Graphics software with layers** such as Photoshop or GIMP (free), to collect and format content
- **Projector, 3000lm or more** For example, Epson 880X (standard throw) and ViewSonic PS502W (short throw) will get you 3000–4000 lumens in the $500–$600 range. DLP projectors are more suitable than LCD. Laser projectors are even better.
- **Cable** to connect the two

For this introductory project, you'll be doing 2D mapping and masking, to project still and moving images. This is the standard for a lot of large-scale building projection mapping. After you master these skills, you can step up to true 3D mapping, where you create the content to suit a 3D model of the target with the projector as a virtual camera.

Build Your Projection Mapping Show

1. TEST YOUR PROJECTOR COVERAGE

We often get asked, "How many lumens (lm) will I need?" Really the answer is, get the brightest projector you can afford — but go ahead and test whatever you can get. We have often been able to use a 4000lm projector outside despite significant ambient light, as we've made content especially for outdoor projection.

Projector Central has online calculators (projectorcentral.com/projection-calculator-pro.cfm) that can help you work out which projector will work in what space, and how large your projection will be at the distance you need to place the projector back from your target surface.

Adobe Stock-pixaroma





Admittedly, we're usually projecting much larger than the recommended maximum size in the specs, but most projectors will still focus. (The exception to this is ultra-short-throw projectors like those used in classrooms, which sometimes have a fixed focal distance and therefore a maximum size they can project. Probably best avoided for our purposes.)

Alternatively, you could just turn on whatever projector you've managed to get and point it at your garage or wall to have an idea of the coverage you'll be able to get from the distance you're limited to. Most projectors will be set to project just blue without a signal (Figure A), but you could cable it to your laptop and set a test pattern or solid color as your desktop, and then extend your display to an external monitor (not mirroring/duplicating it). We'll assume you know how to do this!

This is a good stage to also scope out ambient light, and whether there's anything you can do to reduce it. If you can't turn off a light that's falling on your target surface, perhaps you can remove the lamp, or mask it in the direction of your surface with foil or something else that isn't flammable. This isn't as necessary if you have a big, powerful projector, but if it's just a home theater or boardroom one, then anything you can do to reduce the ambient light is worth doing.

This test will also show you which of your surfaces will hold projection. For example, if you have windows, you might need to put up cardboard or curtains to hold the image. Bright surfaces are much more effective than dark surfaces, so this will help you plan where to put your content.

2. PHOTOGRAPH THE BUILDING

2a. Take a photo of the building in the daytime from approximately where your projector will be located. Frame it to include all of the building you could cover at your projector test.

Back in the day, this needed to be done very accurately with a lens that matched that of the projector. Happily, these days, it's easy to adjust your mapping digitally on the fly — so this photo is really just to design your display and understand what shapes you'll want to create (or source) your content in.

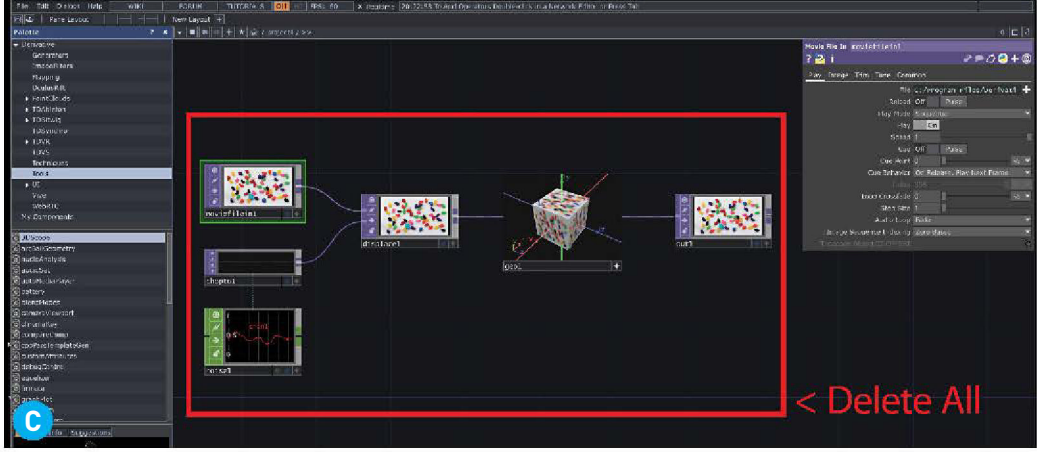
2b. Crop your photo to the maximum coverage of your projector (from your test), then resize it to 1280 pixels wide.

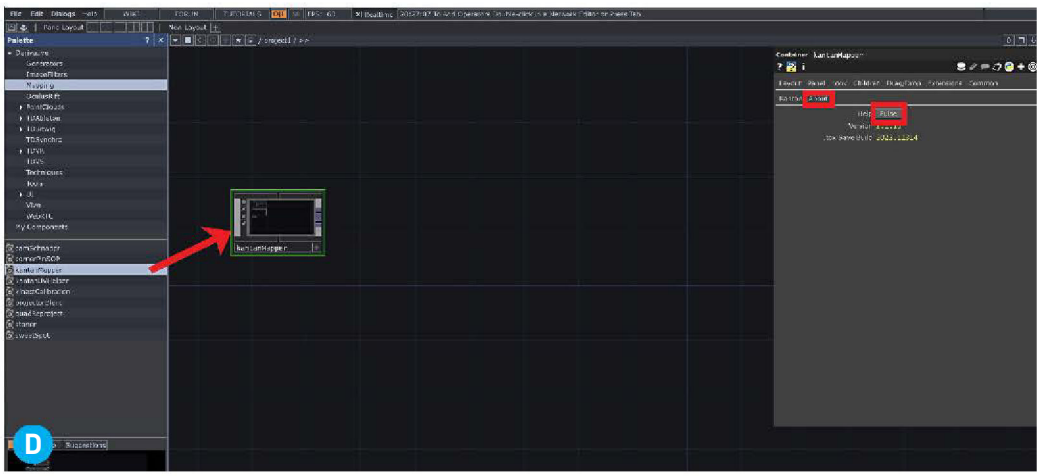
Now "pad" it to be the same aspect ratio as your projector (usually 16:9 or 16:10, or if you're using an older projector it might be 4:3). In Figure B, the green portion shows where we padded extra space on the sides so the final image is 1280×800 pixels (16:10 ratio).

3. SET UP THE SOFTWARE

Download and install the non-commercial version of TouchDesigner from derivative.ca. This will allow a maximum canvas size of 1280×1280 pixels. This means that if your projector is higher resolution than 1280 pixels wide, your content will be upscaling, so it won't look as good as if you were using the commercial version of TD — or something like Resolume Arena or MadMapper — but it's pretty good as a no-cost option! It also has integrations to Ableton, Adobe Illustrator, Kinect, and other platforms that are fun to play with.

Resolume Arena and MadMapper are both easier to use and have a free trial — but they both brand the image output in their free-trial versions, so we've gone with TouchDesigner so your Halloween display won't be interrupted by branding.





4. MAKE YOUR SLICES IN TD

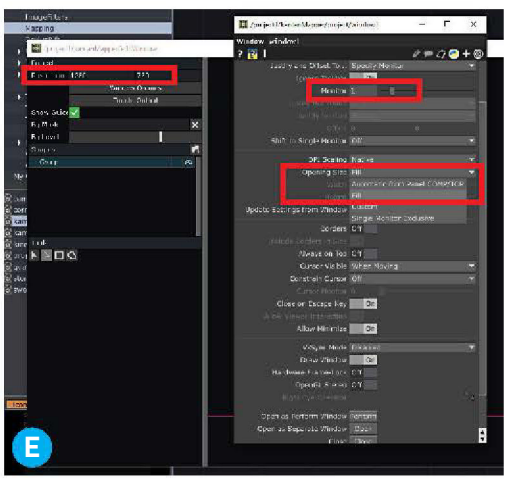
Using your photo and coverage test as a guide, you will create each "slice" of your surface that you want to be able to individually put content in.

4a. Delete all the demonstration starter nodes (Figure C), or start a blank project with File→New. Save your project with a new name.

In the Palette menu, click Mapping and then drag Kantan Mapper onto the central workspace, called the ***network***. TD often has really useful help documentation, which is the case for Kantan Mapper. Click on About→Pulse to open a detailed step-by-step of how to use this component (Figure D).

Leave that resource open while we demonstrate how to use those tools to map our garage and create a Halloween display.

4b. Connect to your projector, then adjust your computer's OS settings to extend your screen output to the projector. Use "extend" rather than "duplicate" or "mirror" options.



In Kantan Mapper, assign the projector as your output and set the projector resolution (Figure E). Usually your main screen is 0 and your projector or second screen is 1, so choose 1 in these settings. When you hit Toggle Output, if your main screen goes black the monitor number is most

likely incorrect — just Alt-Tab (or Command-~ on a Mac) to get back to the Kantan window to toggle it off and try the window options again (Figure F).

If the native resolution of your projector is higher than our limit of 1280 pixels wide, calculate the closest corresponding resolution with the same aspect ratio. For example, for a 16:9 ratio, use 1280×720 (720p) for 1920×1080 (FHD); for a 16:10 ratio, use 1280×800 (WXGA) for 1920×1200 (WUXGA).

4c. Drag your resized photo into the network workspace. Position it high enough that you can still see it when you toggle the Kantan Mapper window back on.

Drag your background image from the network workspace to the Bg Mask field of the Kantan Mapper window, and check the box next to it by clicking the X (Figure G). Your background image will now appear at the default of 75% opacity.

Now you'll trace out all your shapes or ***slices*** — see the Kantan Mapper Help for detailed instructions for doing this. Name each shape as you draw it, and don't forget to save your project (*.toe*) file and mapping (*.json*) file regularly as you go. These are both very small files, so keep a number of iterations back. TD will save a project every time as a new file by default.

We've used the freeform tool here, and have created a slice for each area that we want to be able to fill separately, as well as a slice for the whole building so we can add a cohesive background pattern if we want to (Figure H).

The eye icon next to each layer toggles the visibility of the slice on and off. One thing worth noting is that the lower the layer in the list, the further "in front" that slice is, unlike Photoshop, Illustrator, and many other programs. In our example project file you'll see that the downpipe, awning, and gas pump slices are lower down the list than the building pieces behind them.

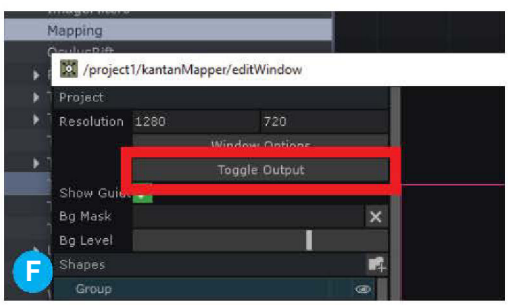
We've organized all our slices in one group, but if your building is more complex you might wish to use multiple groups to keep track of your slices.

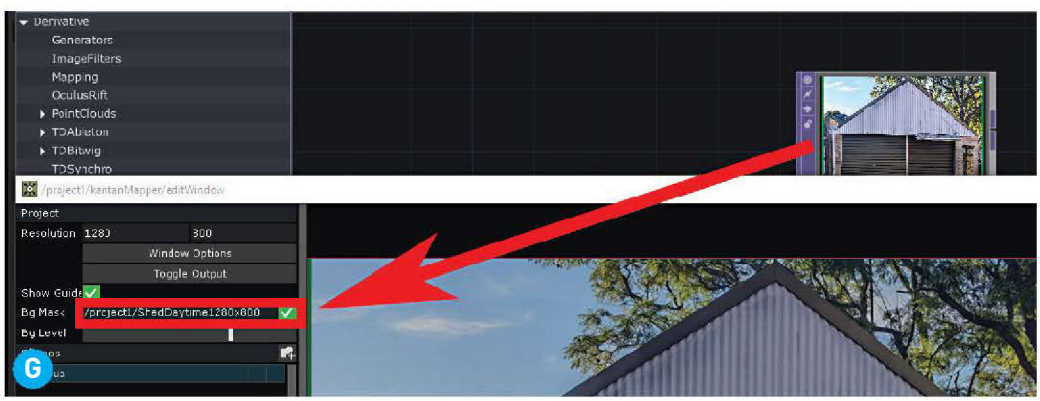
4d. Now you'll export your map so you can use it as a template in your content-making workflow. Double-click in a blank area of the network space and select TOP→Movie File Out (Figure I).

Then change the Movie Out settings: set Type to Image, and set Movie Pixel Format to PNG to maintain transparency (Figure J).

Now select one slice at a time and export each to an individual PNG. Make sure to rename the file each time to the name of your slice, or it will overwrite the previous one. To save the PNG, toggle Record to On then back to Off.

To get the Kantan Window up at any point to access your slices, click on it in the network workspace then hit Pulse next to Open Kantan Window.





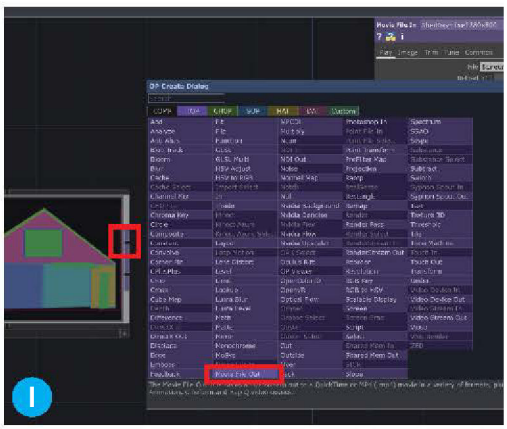


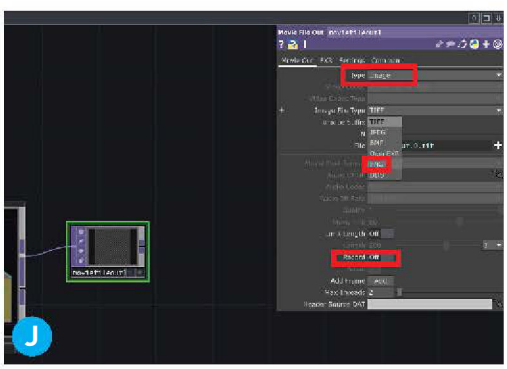
4e. Once you've saved all your slices as PNGs, you can paste them all into a layered Photoshop file so you can work on your content as a whole composition. Work out the dimensions of each slice, round up to the nearest 20 pixels or so to allow for tweaking later, then type those dimensions, as well as the slice name, into the layer, as you will need this info later. For example, *TopTriangle 1200x400* is one of our slices.

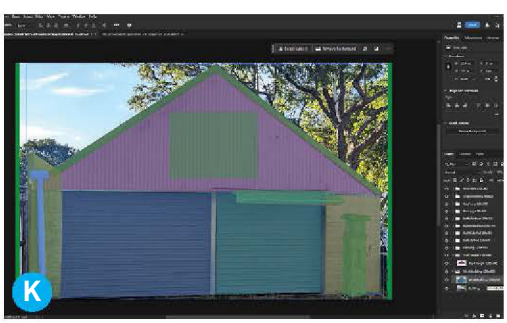
If you're using Photoshop to collect and size your content, you could make each slice a layer-folder and put content into each so you can easily turn the slices on and off, or change the opacity to see underneath a slice.

If you have something you want to mask off such as a reflective window, you can make a slice and fill it with black, as black does not project.

Now paste your building photo underneath so you can see each surface (Figure K).







5. CREATE OR SOURCE YOUR CONTENT

Now that you know the sizes and shapes of your slices, you'll need content for each of those slices. While you can stretch content to fit any shape, it looks best if you keep the original aspect ratio, so keep that in mind when creating/sourcing your content.

TIP: If you're using AI to make content, prompts such as "high contrast illustration, simple, bold, black background" will show up best, especially if you have an underpowered projector. Some AI programs will even let you specify aspect ratios; for example, for the skeletons we made in Midjourney for this project, we specified a 1:3 ratio to fit on the upright of the garage. Some can also create repeating patterns, which make good backgrounds.



You can also create or source still images, animated GIFs, or video animations from 2D or 3D programs. A wide range of formats are accepted by TouchDesigner. TD also supports alpha (transparency) as long as your file format also supports that.

We absolutely love old films, and a lot of old black-and-white horror films are now public domain. You can download full movies from archive.org and edit your favorite scenes, or just play the whole movie. These are generally 4:3 ratio, so having a slice somewhere on your building that's 4:3 would really suit these old movies. Some of our suggestions for Halloween are: *The Cabinet of Dr. Caligari* (1919), *Haxan* (1922), *Nosferatu* (1922), *Dracula* (1931), *Frankenstein* (1931), *Bride of Frankenstein* (1935) and *Betty Boop Minnie the Moocher* (1932). You can edit scenes from these for free in DaVinci Resolve. They don't need to be any higher resolution than the slice on your map, so if you edit to that size then your files will be smaller and create less overhead in your project.

Sort your content into a folder for each slice, and name it with the slice name and dimensions from Photoshop. Keep your maximum dimension to 1280 pixels and your minimum no smaller than the slice size. Also make the content the correct proportion for each slice, to stop it looking too distorted.

If you're making your content as a layered composition in Photoshop or AfterEffects or similar, export each layer trimmed to the approximate slice dimensions, with alpha if required. At this stage, it might be easier to make a cropped Photoshop composition for each slice so you can just do an automated Export Layers to Files at the correct size for each slice.

If you have content that's long in duration, like the old movies we're using, then these also don't need to be the full composition size, just the size of the slice or a little larger. We have made them 320×240 pixels with audio in H264 codec in DaVinci Resolve. This codec is a small file size, but can only play in one direction, which is fine for this application. If there's transparency, for example with your animations, you will need to use a codec that supports that, such as HAP, or make an animated GIF.

TIP: As TD will play everything that you place directly in the slice's folder, we find it useful to have a *NotUsed* subfolder in each slice's folder. This way you know where to look and can drop content in and out of the show by moving it between the top level of the slice's folder and the *NotUsed* subfolder within it.

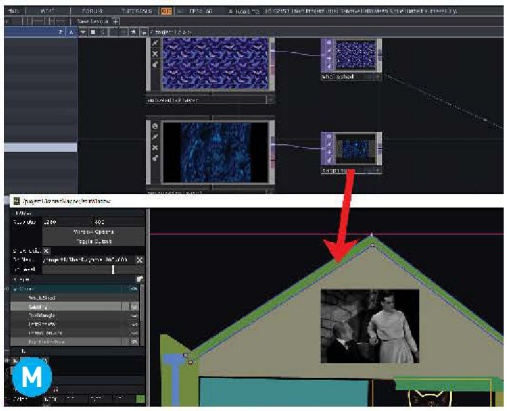
6. ASSIGN CONTENT TO SLICES

If you're making just a simple scene and don't want to change any of the content during the show, simply drag the content for each slice onto your network workspace, then drag each piece of content into the appropriate slice in the Kantan window.

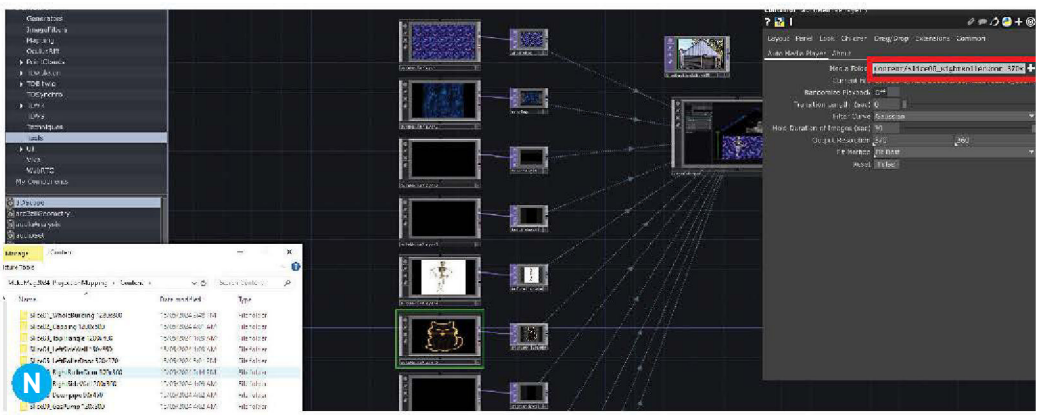
For Halloween we're assuming you might want to change the content in each slice throughout the show, so we're adding an AutoMediaPlayer and Null to the network workspace for each slice. Add the first AutoMediaPlayer from Tools→ AutoMediaPlayer to the network workspace, then right-click on the purple Output node to bring up a dialog box and select Null (Figure L).

Once you have this pair, select them by right-clicking and dragging an area that includes them both, then copy them by Crtl-C (or Cmd-C on a

Mac) and paste as many times as you have slices by Ctrl-V (or Cmd-V on a Mac). Rename each Null to the name of the slice that the content will be for. Reopen the Kantan Mapper window by clicking on it in the network workspace, then drag it to the side so you can see all your slice names. Toggle the Kantan window back on and select each slice and drag the named Null for each slice to that slice (Figure M).



Now select each slice's Auto Media Player and assign the folder for the content (Figure N). Go through the fields below this and Randomize Playback if desired, set Transition Time, Hold Duration, Fit Method, and the Output Resolution. Aren't you glad we put that in the folder name now?



Your show should now start to take shape! Open the Kantan window and/or output to your projector to see how it all looks. You will probably want to go back and tweak the content now that you can see it all playing together.

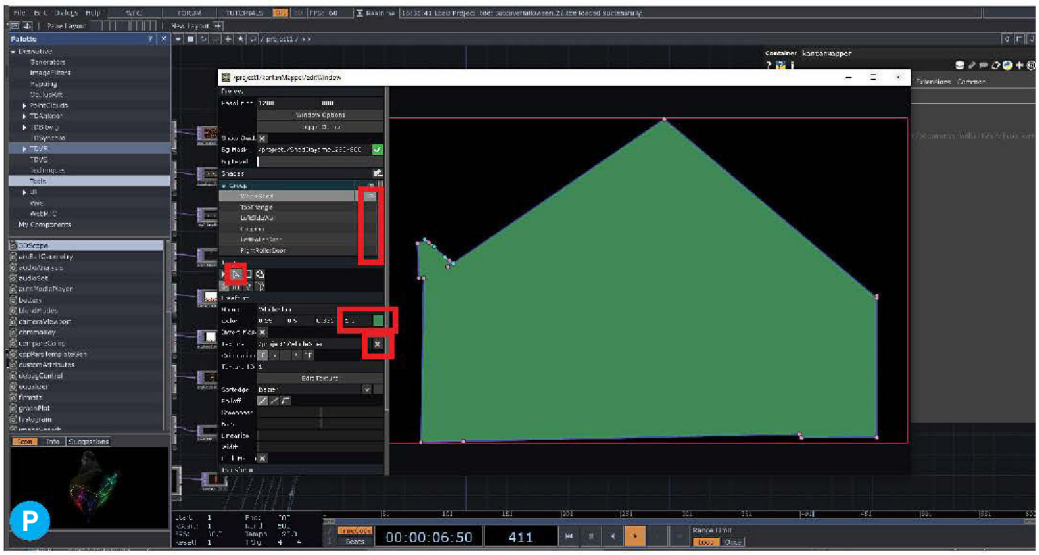
You might even want to add some new slices as you work on your overall composition. For example, we thought a rustic wooden frame would look good around our old movie Insert, so we made an extra slice for that.

7. TEST AND TWEAK *IN SITU*

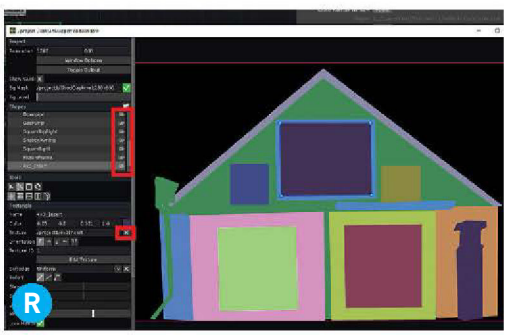
Set up your projector where you get full coverage, ideally centered on the building. It's OK if you have to be off to the side a bit — the middle of your driveway probably isn't the safest place. If your projector is set to blue when there is no signal, use that to work out where you should set up your table. You're aiming to get full coverage without too much wasted light spill.



Cable your projector into your laptop and boot up your project in TouchDesigner. Toggle your Output on in your Kantan Mapper window. It's likely that your slices will all be way off, as you're probably not in the exact same spot where you took the photo, and it's likely your camera lens has a different focal length than your projector lens. It's fine though! Even ours started out wonky (Figure O).







Line up the slices one at a time. Turn off the visibility for all the other slices, and uncheck the content Texture field so you get the solid color for the slice showing. Then choose the Select Keys and Handlers tool and move each point of the selected slice around until it's in the right spot on the building (Figure P).

Continue slice by slice until you have all your slices in the right place on your building (Figure Q).

You can change the layer order by dragging them in the Kantan window list (Figure R). Remember, the lower in the list, the further *in front* of the other layers (which is the opposite of many other programs).

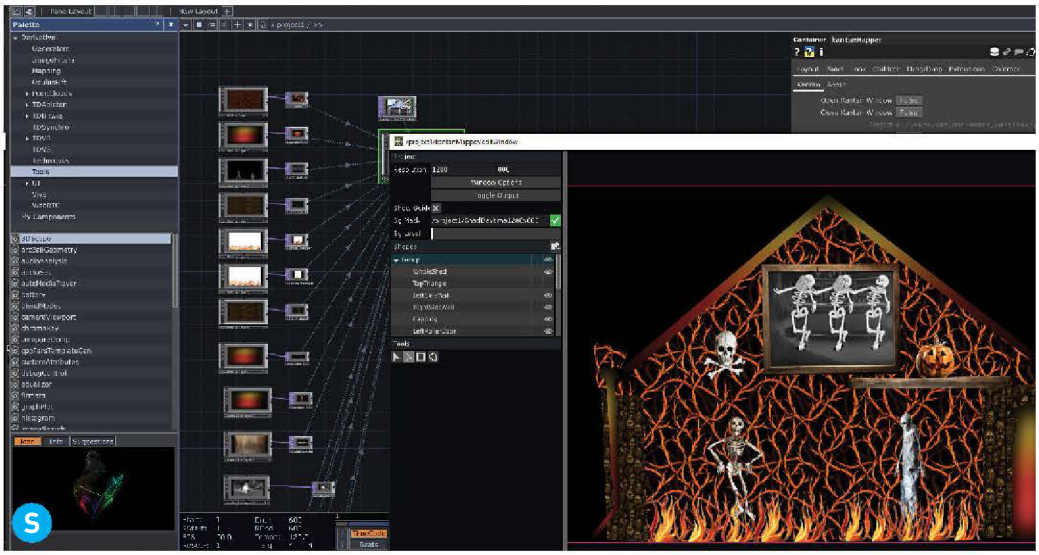
Now your slices are all in place! Check the content Texture for all the slices (Figure S), and turn off the eye for any slices you don't want visible.

No matter how long you've put into getting your content just how you like, there's no substitute for testing *in situ* (Figure T). You may have to edit your content to make it fit the slice better without looking stretched. Experiment with different Fit methods in the slice if your content isn't all appropriately sized or leaves gaps showing. Fit Best, or Fill, are usually good options to start with.

Finally, if there's anything unsightly or reflective in front of any of your slices, you can add more slices and fill them with black.

Fantastic Phantasms

Now you're ready for your Halloween projection show! And there are so many things you can do in TouchDesigner in addition to this basic mapping. For example, you could have your content be audio reactive, or change colors over time. You can adjust the levels of any particular slice to account for a darker surface. You could flip the content back and forth, or rotate it slowly. You can



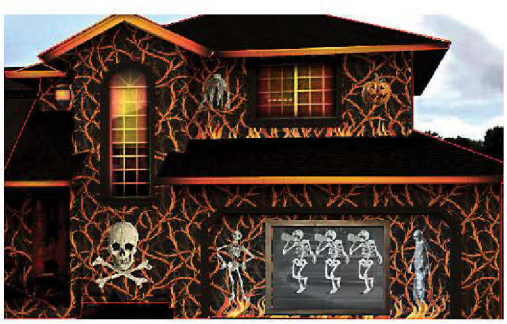




procedurally generate patterns using noise, or add interactivity.

There are many TouchDesigner tutorials online, and it's very adaptable and stable software — even if the interface isn't as user-friendly as more commercial alternatives. The Interactive & Immersive HQ (interactiveimmersive.io) does great TD tutorials, including a free Beginner Crash Course on their YouTube channel.





"I can see my house from here!" The authors mocked up the editor's home as a Halloween show.

MAPPING RESOURCES

- Our Halloween graphics content to get you started: makezine.com/go/vjzoo-halloween
- TD tutorials at youtube.com/c/theinteractiveimmersivehq and derivative.ca
- Software to create and edit content: DaVinci Resolve (free), AfterEffects, Unity (free), Unreal Engine (free)

Electromagnetic Symphony

Make EMF radiation audible and listen in to the silent backbone of our electronics society

Written and photographed by Darcy Neal



DARCY NEAL is a new media artist, educator, and builder of custom interactive objects. With a background in sculpture, electronics, and experimental music, their work is focused on tangible sensory exploration through electronic interfaces and creating new ways of interacting with our world. darcyneal.com

We are surrounded by electromagnetic forces, which go largely undetected but are vital to modern technology. Electromagnetic field (EMF) radiation comes from natural phenomena like the planets in our solar system, the heat of a burning fire, the lightning from a storm, and even the beating of a heart. It also emanates from human-made inventions like cellphones, Wi-Fi and other radio signals, lightbulbs, X-rays, microwaves, and much more. Anything that produces an electric current will emit EMF radiation, creating invisible electronic fields all around us. The EMF Explorer project offers a unique opportunity to tune in and listen, by transforming electromagnetic activity into audible sound. It's like giving a voice to the silent but constant companions of our electronic era.

THE EMF EXPLORER PROJECT

While this circuit amplifies the majority of EMF signals it picks up, we will only be able to hear those that fall within the frequency range of human hearing, about 20Hz–20kHz. This also happens to be the frequency range that most of our electronic appliances operate within! Imagine hearing the electronic operations of your cellphone, the rhythmic patterns emitted by Bluetooth headphones, or the electronic harmonies of countless devices whirring along in our lives. This article will guide you through creating your own EMF amplifier at home with minimal parts.

Originally used in an exploratory electronics soldering workshop, this project allows participants to assemble their own EMF Explorer PCB. Inspired by Jonas Gruska's Elektrosluch circuit (makezine.com/go/emf-microphone) and DIY Circuits' Electromagnetic Field Detector (instructables.com/Electromagnetic-Field-EMF-Detector-With-LM358), the circuit was modified to use a smaller battery source, simplified voltage divider, different amplifier, and low-pass filter, and optimized to be worn as a wearable PCB badge (darcyneal.com/emf-explorer-badge). This badge encourages participants to explore the electronics world around them and opens up opportunities for learning about physics, electronic theory, audio applications, and more. It requires only basic electronics

TIME REQUIRED: A Weekend

DIFFICULTY: Beginner to intermediate

COST: $15–$20

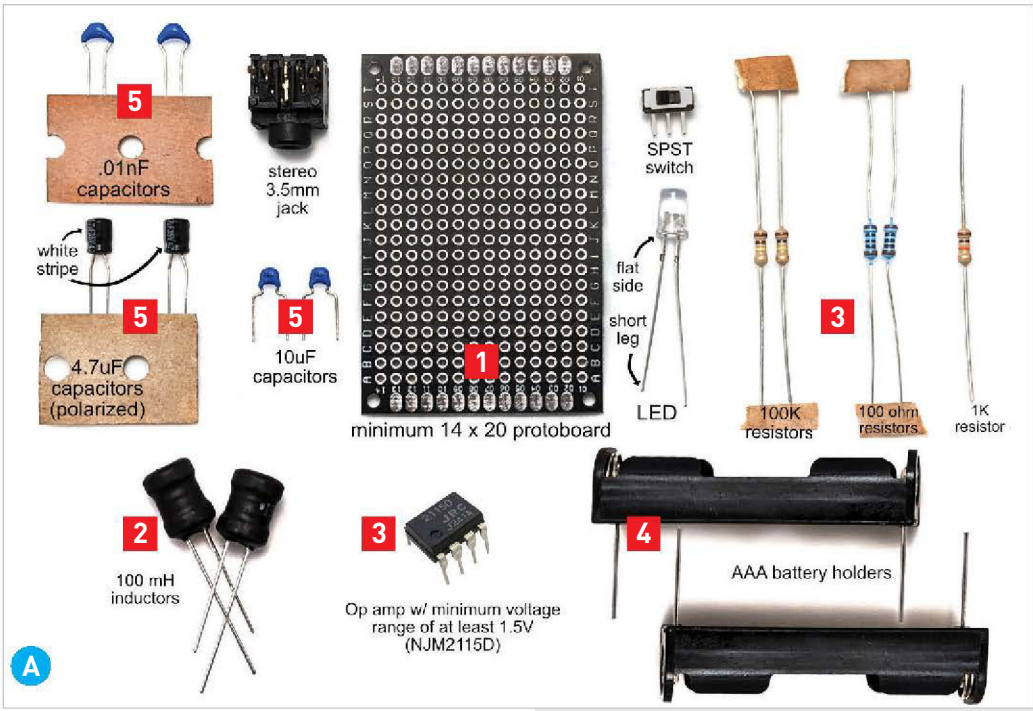
MATERIALS

All part numbers from Mouser Electronics, mouser.com.

- **Protoboard, at least 4cm×6cm** Mouser 485-4785 mou.sr/499JZ11
- **Op amp, dual channel** 513-NJM2115D mou.sr/3TwkQHZ
- **AAA batteries (2)**
- **AAA battery holders (2)** 534-2466 mou.sr/3Xb8s0H
- **100KΩ resistors (2)** 603-CFR-25JB-52-100K mou.sr/47um9g4
- **100Ω resistors (2)** 603-CFR-25JB-52-100R mou.sr/3VQZZlN
- **1KΩ resistor** 603-CFR-25JB-1K0 mou.sr/3S4nkwA
- **.01nF capacitors, non-polarized (2)** 80-C317C100K2G mou.sr/4au28HX
- **10uF capacitors, non-polarized (2)** 810-FG24X7R1A106KRT6 mou.sr/3szGRw2
- **4.7uF capacitors, polarized (2)** 667-ECA-1HM4R7 mou.sr/3TRmqWm
- **100mH inductors (2)** 652-RLB1014-104KL mou.sr/3VzBQzK
- **Stereo headphone jack** 485-1699 mou.sr/3vvaO1V

TOOLS

- **Soldering iron and solder**
- **Mini wire snips** Mouser 577-170 mou.sr/3VAELII
- **Angled tweezers (optional)** recommended for holding parts while soldering, 474-TOL-10602 mou.sr/49rk0T7
- **Solder sucker (optional)** recommended for clearing accidental solder joints, 485-148 mou.sr/4cpWGI1
- **Wired headphones**



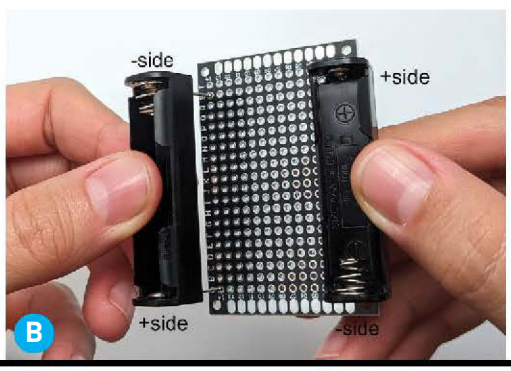
know-how and just a handful of components (Figure A).

CRAFT YOUR EMF AMPLIFIER

1. PLACE THE BATTERIES

Before you begin soldering, make sure you're working on a heat-resistant surface and have ventilation for the solder fumes.

The battery holders take up a bit of space on the board; add those first so you'll know how much room you have for the rest of the circuit. Place them on the outermost sides, and leave an open row at one end so that they take up the least amount of space possible. Make sure the position and polarity of the batteries match what you see in Figure B.



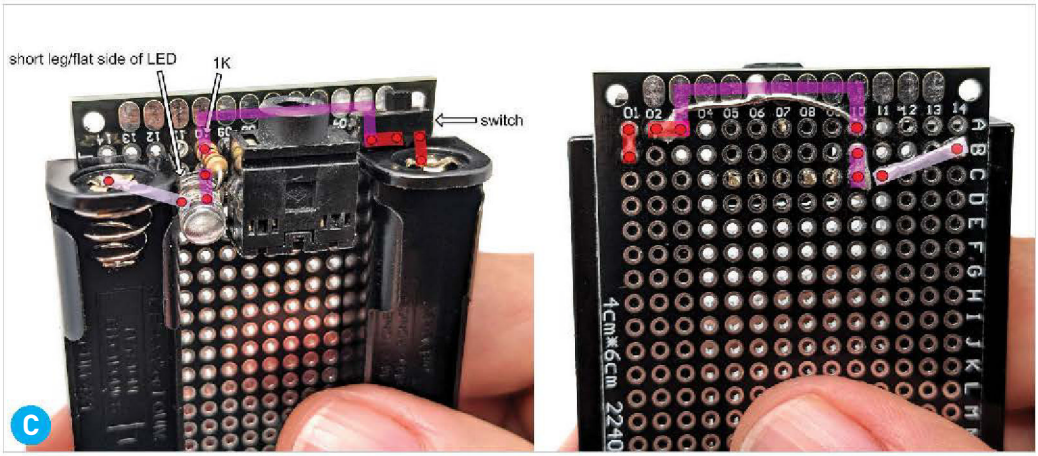
1. **Protoboard** lets you solder the connections in a durable configuration that should last years.

2. **Inductors** are the "sensors" that pick up EMF frequencies and translate them into a measurable signal. Inside are tightly wound coils of wire which, when exposed to an EMF signal, will react and generate a current from the electromagnetic waves in the air.

3. **Op-amp and resistors** amplify the inductors' signal to be loud enough to drive a speaker. We wire up the operational amplifier to create an inverting amplifier, whose gain is determined by the two resistor values connected to the op-amp.

4. **AAA batteries and holders** provide the necessary dual-voltage supply for the op-amp.

5. **Capacitors** sculpt the signal, shaping and filtering the electromagnetic waveforms. The .01nF capacitors help to stabilize the output of the op-amp from the massive gains we are pulling from it. Optional 10µF capacitors act as a low pass filter, cutting out some of the high frequencies for easier listening. Experiment and decide which sounds you prefer.



Add the LED, LED resistor (1K), and switch, and place the output jack, as shown in Figure C. You won't solder the jack quite yet, but snap it into place now to ensure everything will fit. The red dots indicate the holes that each component is placed through, and the color stripes indicate the connections on the underside of the board.

When soldering together components, use the leftover length of the leads to help make the necessary connections. The short leg/flat side of the LED will connect to the negative (–) battery terminal, and the long leg will connect to one side of the resistor. Connect other leg of the resistor to the switch, being sure it doesn't touch the jack. Notice how I soldered the LED leg to one of the outer pads to help ensure that it never touches the jack.

Once everything in that section is soldered up, cut the remainder of the leads off.

3. AMPLIFY YOUR SIGNAL

In order to hear the signals being picked up by the inductors, we need to amplify them up to human hearing levels. The resistors determine how much the op-amp amplifies the incoming signals from the inductors.

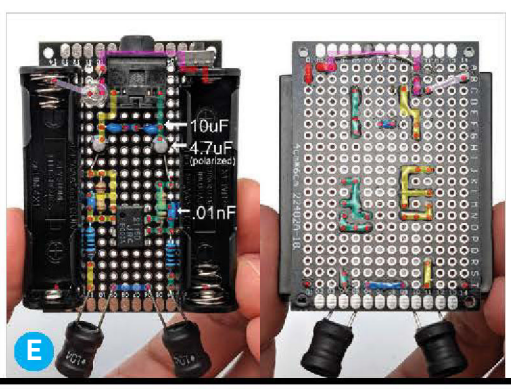
Add the inductors, the four remaining resistors, and the op-amp IC as shown in Figure D. Make sure that the black dot on top of the IC matches the orientation shown, and that the resistors are connecting to the correct legs of the IC. Solder the connections together, again using the leads to help make the connections, then trim off the excess leads.

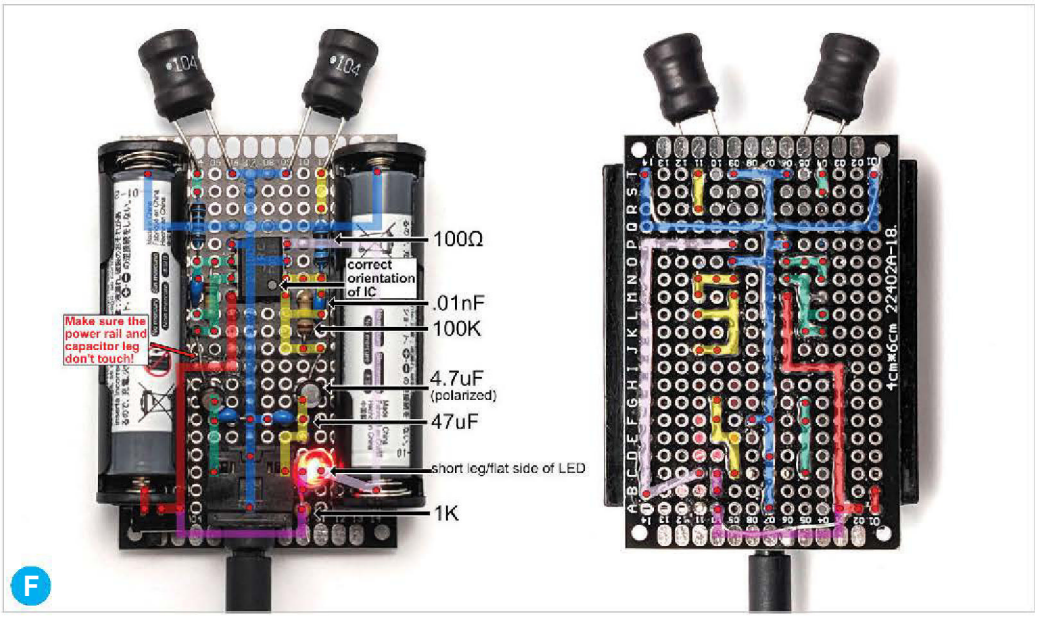
4. ADD THE CAPS

Now you'll add all the capacitors and connect them into the audio jack outputs. For this part, you're going to run the positive leg of the 4.7µF capacitors on the top of the board, toward the resistors (Figure E). Notice that the 4.7uF caps are polarized, meaning the orientation of the white stripe needs to match what you see here. Place a piece of electrical tape or paper underneath the topside leg to make sure it doesn't touch any other pads on the board, as you will later be running power across the underside.

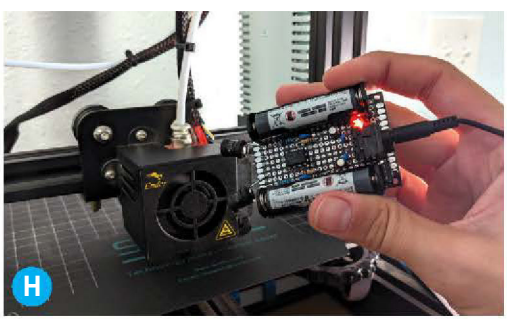
Make sure everything is laid out correctly before soldering in place.

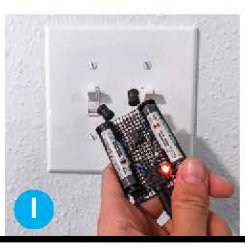


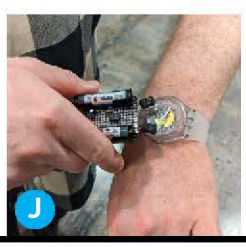












5. LAY OUT THE POWER!

Finally, add the power distribution across the board. Connect the remaining four legs of the IC, the center trace that connects the inductors, the 10µF caps, and the ground pin of the audio jack to the appropriate power rails, as shown in Figure F. For connections along the longer traces, you may want to use some of the excess leads you trimmed from the other parts.

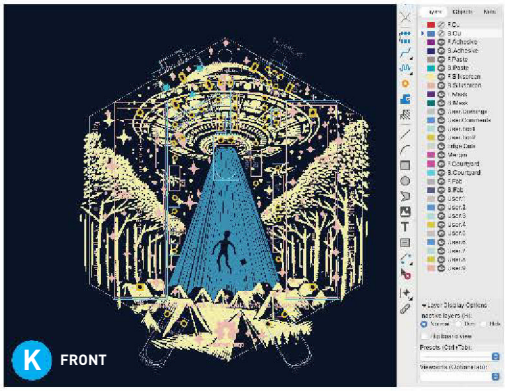
6. INSPECT AND TEST

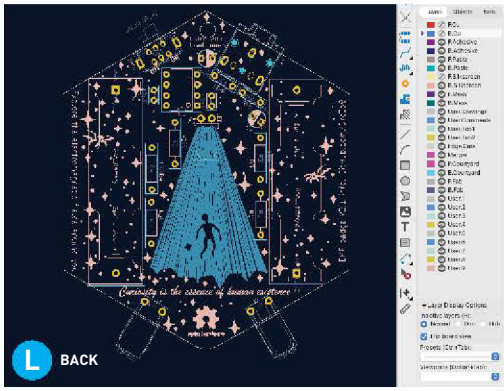
Take a moment to carefully review your board and ensure that everything is connected as it should be. Trim off any excess leads.

Now you can add the batteries and plug in your headphones! Bring your EMF sensor close to a powered electronic device like a computer, phone, wireless headphones, etc. You should hear a buzzing sound as you get closer to the power source (Figure G).

THE ADVENTURE BEGINS

With your EMF amplifier in hand, it's time to go exploring. Venture out to discover the hidden electronic symphonies around you. Each electronic device offers a unique acoustic signature, from the bleeps of Bluetooth headphones to the varied sounds of different gadgets. How do a computer's sounds differ from that of a lightbulb? Can you distinguish a





cellphone's different chatters coming from its various components? See how many types of sounds you can discover (Figures H, I, and J).

You can also experiment with different component values to adjust the gain, low pass filter, inductor size, and more. This op amp uses the same footprint as many other common two-channel op amps, so you should be able to swap that out as well if you'd like, but be aware of the pinout and min/max voltage limits of the op amp you're choosing.

A PORTAL TO THE INVISIBLE

The EMF Explorer project is a gateway to building a deeper understanding of our surroundings and the complex electronic ecosystem that supports our modern life. As a continuation of this project, I've designed this circuit into a wearable art PCB (printed circuit board) using KiCad, an open source PCB design software. I did this by hacking the technical layers that make a PCB and repurposing them as visual art layers. Like painting on a canvas, the elements of a circuit board can be used for visual imagery.

To do this, I created vector images for each PCB element and then assigned them to the appropriate layers in KiCad, which includes the copper layers, solder mask layers, and silkscreen layers, all of which can be used in nontraditional ways to create a unique color palette (Figures K and L).

To learn more about the PCB design process and the EMF badge itself, check out my website (darcyneal.com/emf-explorer-badge), or you can buy the kit on the Maker Shed (makezine.com/go/emf-badge)!







Solar Plant Rotator

Build a slow-motion spinner for hanging plants, based on BEAM robotics

Written and photographed by Andy T. Evans

This battery-free device will make your hanging plants happy. Powered by the sun, it slowly spins your suspended plant so it receives a healthy amount of light on all sides.

I have always been fascinated and entertained by BEAM robots, and I'm always looking for useful projects to utilize their "solar engine" circuits. So I thought these little solar harvesters would be a great fit when I was trying to think of an automated way to rotate my very lopsided fern plants, which were unfortunately not close to any power outlets.

Because my plants are heavy, I wanted to make a design that could hold a lot of weight. So I used a metal U-bolt, hook, and a strong but light 1" square aluminum tube for the body. But the star of the show is the ***thrust bearing.*** We commonly see roller, pillow, or linear bearings but often forget this type. It's simple, cheap, and can make your project more robust, reducing friction, drag, and wear. It allows this project to use a small, cheap toy "TT motor" to rotate a large load easily.

BEAM DESIGN

A tiny solar cell produces far too little power to turn a motor directly, but if we store the energy

in a capacitor until we have a larger amount, we can then release it in a big enough burst of power. Mark Tilden, the father of BEAM robotics, along with others, popularized using this ***solar engine*** concept to power their bots in the early 2000s.

BEAMbots are biologically inspired; they utilize salvaged parts, analog circuits, and small amounts of harvested power to move and respond to their environment. There are a plethora of interesting solar engines to choose from, most of which are variations of ***relaxation oscillators*** — circuits that produce repetitive output signals. This repetitive power discharge can do some real incremental work with a tiny amount of energy collected.

For this project, we will use a ***Miller solar engine***, a popular design by Andrew Miller that's versatile and efficient. It is configurable for many uses and can drive both inductive (motors, coils) and non-inductive (LEDs, other circuits) loads, making it ideal for different projects. The Miller solar engine uses a voltage trigger to oscillate, with a discharge time configured by a capacitor value.

KNOW YOUR SOLAR ENGINE CIRCUIT

SOLAR CELL

When sourcing a solar cell, try to find one that produces 5 or more volts. If you can't, that's okay, too, but you'll need to adjust which voltage trigger IC you use.

The beauty of this solar harvester is its versatility. You can often make it work with whatever components you can find or salvage. It will work with even a very small amount of power from a tiny solar cell, sometimes found on broken, discarded yard decorations or path lights. If you do have to buy, Solarbotics sells one with the Miller solar engine circuit on the back, which can be handy if you don't want to build your own board. Anything 28mm–35mm tall should fit well in the enclosure. For the width, anything 20mm–60mm long can fit. I used a common 30mm×53mm size.

STORAGE CAPACITORS

The storage capacitors (labeled C2 and C3 in the schematic diagram and perf board layout

TIME REQUIRED: A Weekend

DIFFICULTY: Easy to Moderate

COST: $15–$40

MATERIALS

- **Axial ball thrust bearings, 8mm×16mm×5mm (2)** Amazon B0BXY9VF8X
- **Aluminum square tube, 1"×1"×5"** Hillman or Steelworks model #11389, Lowes 216099 or Menards 2279987
- **U-bolt, ¼"×1⅛" wide**
- **Hook, ¼"**
- **Lock nut, nylon insert, ¼"**
- **Lock washers, ¼" (2)**
- **Machine screws, #8 (2)**
- **Solar panel, 5V or higher, 53mm×30mm or 37mm×33mm** Amazon B06ZZCV99D or Solarbotics SCC3733
- **DC gearbox motor, 1:48 ratio, 3V–6V, aka "TT motor"** such as RobotShop RBC-Apt-90, Adafruit 3777, or Amazon B0BR7S2TRY
- **Perf board, 11×16 holes, approx. 33mm×50mm** such as Amazon B00PKVSQX
- **Voltage detector, MCP112-315, TO-92 package** The last three digits in the part number (315 here) determine the trigger voltage (3.15V).
- **NPN transistor, 2N3904**
- **Switching/signal diode, 1N4148 or 1N914**
- **Storage capacitors, electrolytic, 6.3VDC, 4700µF (2)** Mouser 667-EEU-FS0J472 or Solarbotics CP4700uF
- **Capacitor, electrolytic, 47µF (1)**

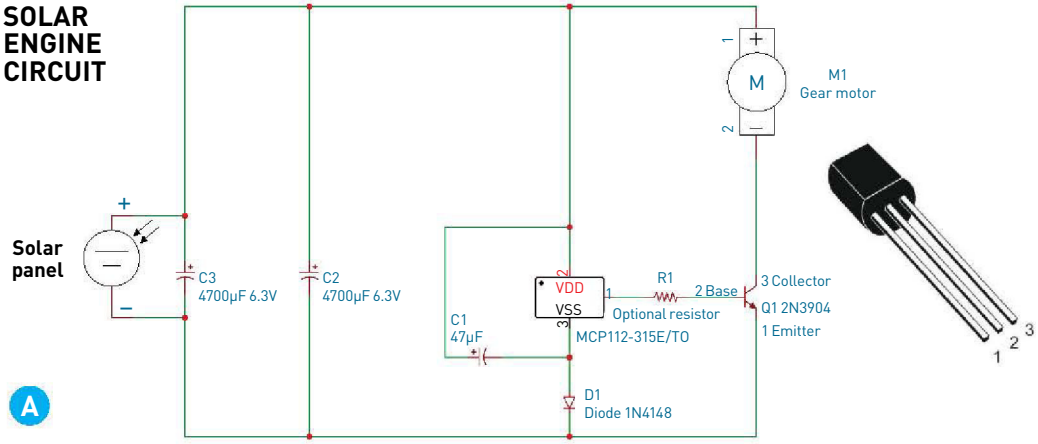
TOOLS

- **3D printer**
- **Jigsaw or hacksaw**
- **Drill with ⅛", ¼", and 5⁄16" bits**
- **Soldering iron and solder**
- **Hammer and punch or nail**
- **Pliers**
- **Flathead screwdriver**



ANDY EVANS enjoys designing and building useful things that no one else has made, and things that bring joy to his family. He lives in South Bend, Indiana, with his wife, two daughters, and Corgi, and loves collaborating with his daughters on interesting projects, even if it leads to funny conversations about the "green stuff my dad and I are growing" (spirulina).

SOLAR ENGINE CIRCUIT



diagram, Figures A and B) act like batteries, so the bigger they are, the longer the power will output, but also the longer they'll take to charge. For our needs, a couple of 4700µF capacitors will store more than enough to get a little movement and charge up in about a minute. Keep the voltage just a little over the maximum your solar cell can output, so in this case, we are using 6.3V capacitors. In order to fit in the enclosure, they should not be much wider than 13mm; the ones I used were 12mm.

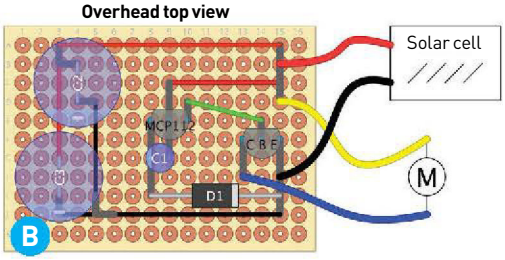
GEARBOX MOTOR

I wanted something cheap, small, and high torque to spin the plant. I had an extra TT robotics gearmotor (M1) with a 1:48 ratio lying around that fit perfectly into the aluminum tube. TT motors can be bought very cheaply, but if you need to upgrade for another project, Adafruit sells some with metal gears and higher-torque gear ratios.

MCP112 VOLTAGE DETECTOR

The heart of the Miller design is the ***voltage detector*** (U1) aka ***voltage supervisor*** or ***discriminator***. It switches on, or *triggers,* when a voltage threshold is reached. That voltage is determined by the version you select; see the chart below. Pick a trigger voltage that is 1 to 2 volts below what your solar panel is outputting in your light conditions. For example, my 5V panel was outputting about 4.5V in my window location under a load, so I chose the MCP112-315, which will trigger the discharge of the capacitors when they charge to about 3.1 volts. If you have a lower-voltage solar panel or don't get much direct light, you might want to pick a lower trigger voltage version. Because they're only about $1 each, I ordered ones with higher and lower values than I thought I would need, to tweak efficiency. You can also add a potentiometer on pin 3 to vary the voltage the detector is sensing, if you want to adjust the trigger point that way.

Overhead top view



VOLTAGE TRIGGER POINTS FOR MCP112 AT ROOM TEMPERATURE

MCP112-195	1.90V (1.872 to 1.929)
MCP112-240	2.32V (2.285 to 2.355)
MCP112-270	2.63V (2.591 to 2.670)
MCP112-290	2.90V (2.857 to 2.944)
MCP112-315	3.08V (3.034 to 3.126)
MCP112-450	4.38V (4.314 to 4.446)

TRANSISTOR

When the voltage on pin 3 reaches the MCP112's activation value, it outputs about 5mA on pin 1.

That is a healthy amount to apply to a transistor (Q1) to turn on the motor. A number of different lower-voltage NPN transistors will work. I used a 2N3904, but a 2N2222 or ZTX450 type would also work.

TIMING CAPACITOR

The smaller capacitor (C1) controls the depth of discharge. Pick something in the 1µF–47µF range. The higher the capacity, the longer the MCP112 and transistor will stay triggered and the deeper the discharge will be. Because the TT motor is not ideal for a solar engine, I maximized how long it's discharging and used a 47µF capacitor. In my testing, this discharges down to less than 0.5V. If you use a lower value, it won't discharge as deeply, and recharging will be quicker, leading to faster cycle times, which could be useful in another project.

DIODE

The diode (D1) plays an important one-way role, directing the timing capacitor's discharge only to pin 3 of the MCP112 and not the rest of the circuit. Without it, the timing cap would behave as another storage cap. Any switching/signal diode like a 1N914 or 1N4148 will work fine.

RESISTOR

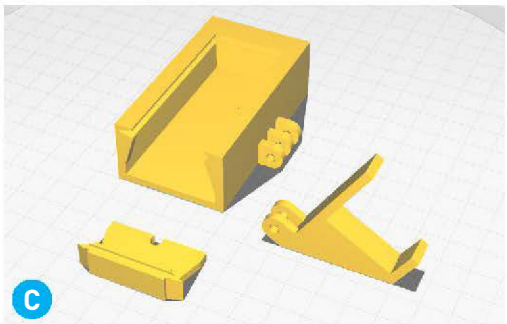
You might have noticed the optional resistor (R1) in the schematic. We don't need it when driving a high load, like this motor, but if you wanted to use this circuit to drive something lower power like an LED, you might like one. If you think of the transistor as a valve, the higher the resistor value, the less open the valve will be. This will lower the output power, but it will last longer, which could be ideal for another project.

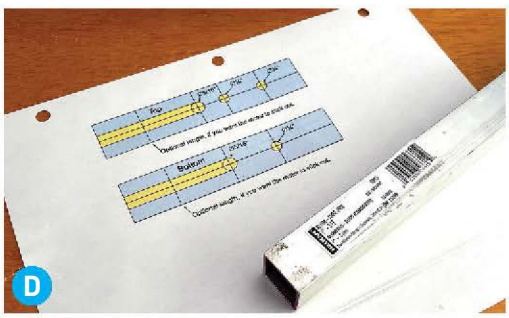
BUILD YOUR SOLAR PLANT ROTATOR

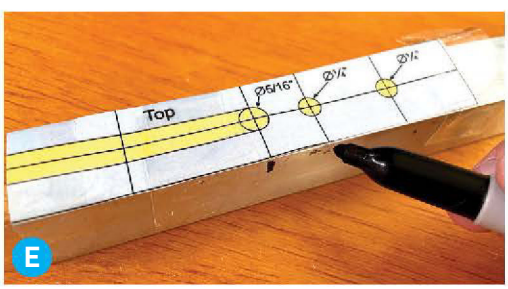
1. 3D PRINT THE PARTS

I designed the parts in Tinkercad (see page 110) to be easy to print without supports; Figure C shows the recommended layout. I sized the enclosure to work with a number of different solar panel sizes. Anything 28–35mm tall by 20–60mm long should fit.

Print the enclosure and gears from the files


C


D



E

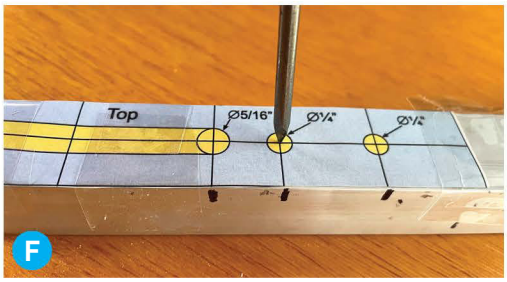
at thingiverse.com/thing:6621988. I used PLA because I intend to use mine indoors behind glass, but if you have direct outdoor light, you might want to consider ABS or another material that will hold up better.

2. CONSTRUCT THE HARDWARE

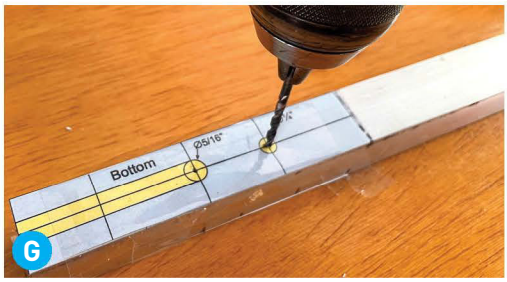
2a. Prepare the square tube

I chose a 1" aluminum extruded square tube because it is strong, lightweight, and easy to drill and cut. If you have some other 1" material lying around, it will work fine as long as the TT motor fits inside.

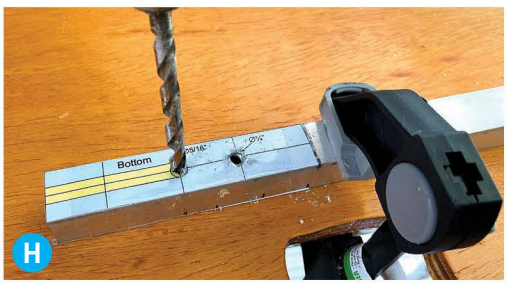
Print the template from makezine.com/go/solar-rotator-template and decide if you want the motor to protrude or be hidden (Figure D). If hidden, use the full length of the template and attach it to the tube. If you like the look of a TT



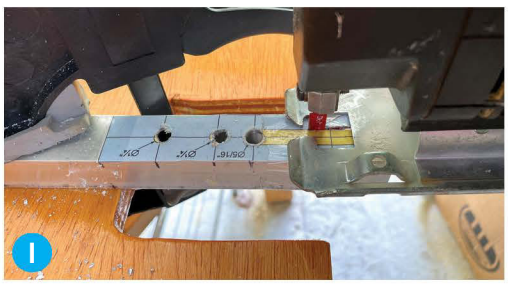
F

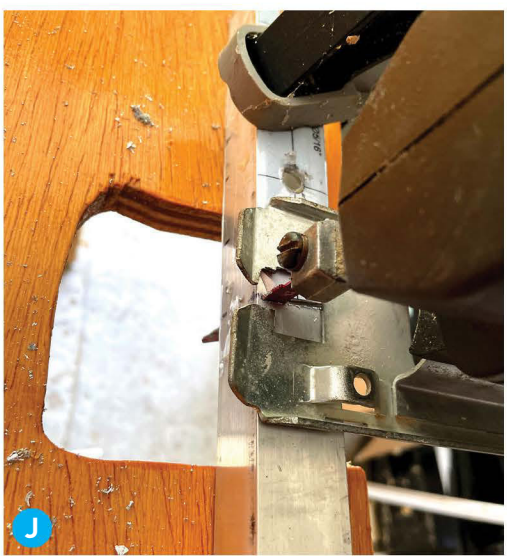


G



H


I


J


K

motor sticking out, you can trim the template shorter. This could also save a little on the amount of cutting you do. Use a marker to mark the center lines (Figure E) and the edge of the cutout in case the template comes off.

2b. Drill the holes

Use a hammer and center punch or nail to mark the holes (Figure F). Then predrill with a ⅛" bit (Figure G) before drilling with the ¼" bit (Figure H). Drill two ¼" holes and one 5⁄16" hole on the top and another ¼" and 5⁄16" hole on the bottom.

2c. Cut the motor slot

Making the two cuts to create the motor shaft slots can be tricky. I found putting the tube in a vise, end up, and cutting down with a hacksaw to the hole edges worked. But clamping it down well to a table and cutting it with a jigsaw worked even better (Figure I). Just make sure your blade is a fresh metal blade and is longer than 1" at its shortest stroke.

2d. Cut to length

Now that you've made all the holes and slots, you can cut the tube to length (Figure J). Be sure to clamp it and go slow if you are using a jigsaw.

2e. Clean up sharp edges

Use a file or sandpaper to clean up any burrs or sharp edges (Figure K). This is also a good time

to clean up any major scratches or marks you might have made on the tube.

You can also polish or paint it now if you like! If you're really ambitious, maybe even do some *perlée*-style engine turning, like on the nose cone of the *Spirit of St. Louis*, with a pencil eraser and toothpaste.

2f. Install the hook and gear

Thread the large gear on the hook. Install a #8 screw into the gear, but do not tighten it yet. Add a thrust bearing to the hook (Figure L). Stack the other thrust bearing and the lock nut over the bottom hole inside the tube.

Now carefully stick the hook into the hole, through the stack, and tighten the nut (Figures M and N). This can be tricky, especially when you get to the locking part of the nut. Unfortunately, most open-ended wrenches don't fit inside the tube. I did find one of those cheap wrenches that come with flat-pack furniture that happened to fit. Glad I saved it! If you don't have one of those, a flathead screwdriver can be used to hold the nut while you turn the hook to tighten it.

Now rotate the large gear on the threads to move it up snugly against the bearings. You want it as tight as it can be while the bearings still spin freely. Then tighten the locking screw into the gear (Figure O). If the screw is slipping, you can add a nut into the slot in the gear.

2g. Install the U-bolt

Screw two nuts onto the U-bolt and add two lock washers. Screw them on plenty far. Put the U-bolt in the top holes of the tube (Figure P), and then install two nuts on the inside with your fingers. Lastly, tighten the nuts on the outside (Figure Q).

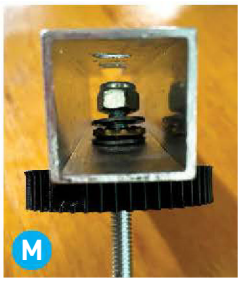
Now you're done with the hardware!

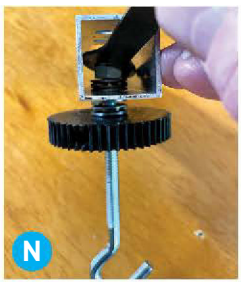
3. SOLDER THE ELECTRONICS

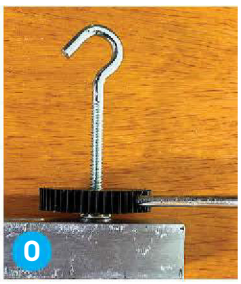
3a. Prep your perf board

You only need about 11×16 holes or 33mm×50mm for this circuit. Snap or cut your board to size; just make sure it's not taller than 33mm, or it won't fit in the enclosure. I like to use the snappable, two-layer variety with plated holes because it is a bit easier and more forgiving, but whatever you have will be fine. This is a good time to lay out all your components as well (Figure R).


L

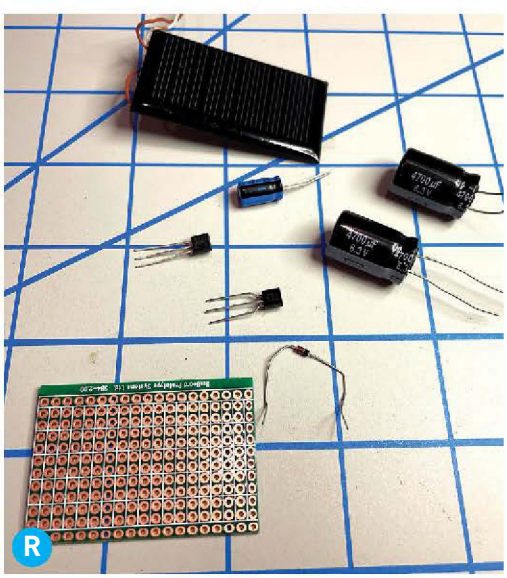

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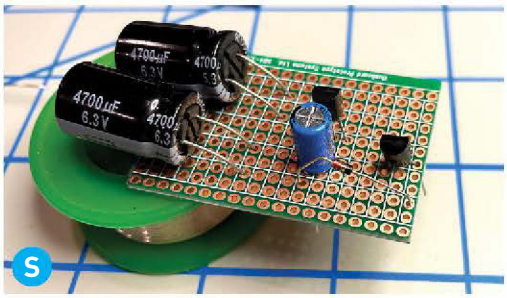

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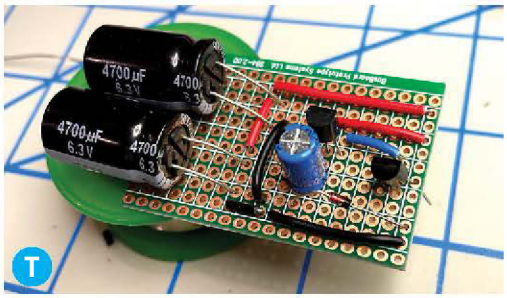

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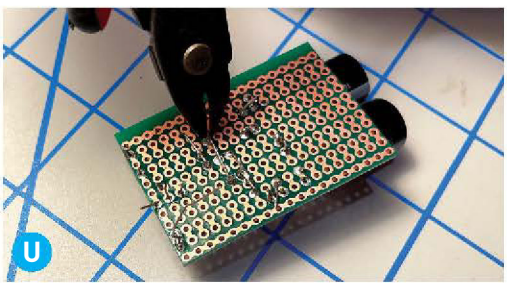

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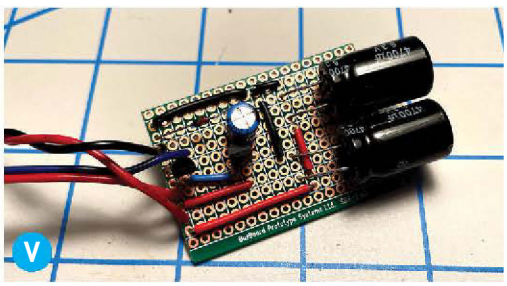

Q

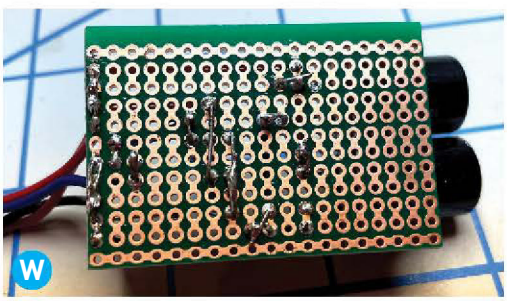

R

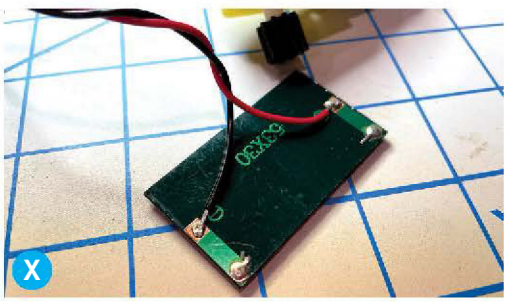












3b. Populate the board

Following the layout diagram Figure B, populate all the major components of the board (Figure S). The larger capacitors will lie on their sides, off the end of the board. When it's clear they will all fit fine, go ahead and solder them in from the bottom. Be careful not to overheat the transistor or voltage detector; to be safe, you can temporarily add an alligator clip to their leads to act as a heatsink. Do not cut off the leads, you will need them to make connections later.

3c. Add the jumper wires

Now add all the jumper wires and solder them into place (Figure T). Again, do not trim them.

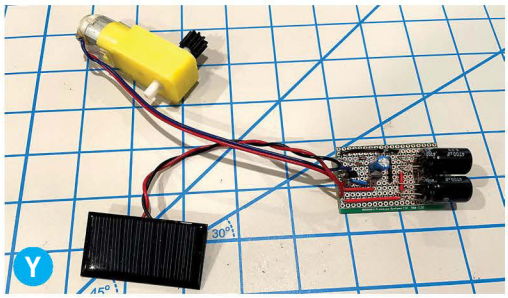
3d. Make the connections

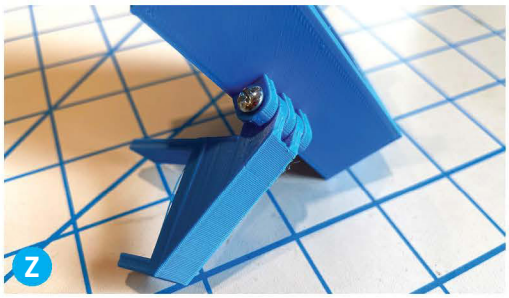
On the bottom, bend the leads over where needed to make the connections colored in silver on the layout diagram. If you can't use extra leads, you can add some extra solder to bridge the pads . After you've made all the connections, use edge cutters to trim off the extra leads (Figure U). Perf board connections are a bit more art than science. There are a number of ways to make these connections, so have some fun!

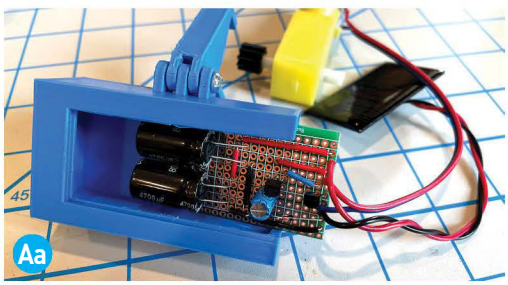
3e. Connect the motor and solar cell

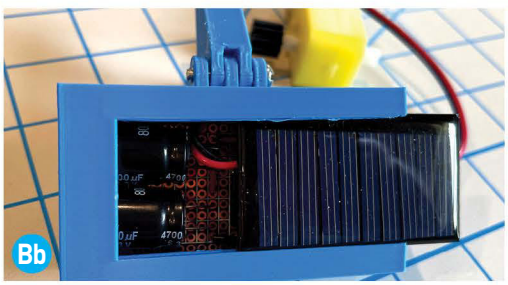
I try to use flexible stranded wires for the motor and solar cell (Figures V and W), rather than the solid-core I use for jumper wires. Optionally, if you heat up the wire a bit and then push it against the board, it will mushroom the melting insulation a bit and give it some stress relief.

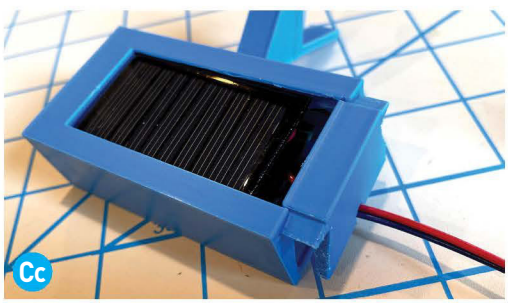
Make sure you connect the solar cell last (Figure X). Otherwise, it can slowly charge the capacitors while you're working, giving you an unpleasant surprise if you short them!













3f. Test it!

You can put your solar cell by a window or lamp to test it (Figure Y). It takes about a minute to charge the capacitors to 3.1 volts, and then it should trigger, and the motor should tick about one tooth width of the gear.

You can hook up a voltmeter on the legs of one of the bigger capacitors and watch the voltage slowly climb and then fall back to 0V again when it discharges to drive the motor. Hours of good, clean fun watching this oscillate!

4. FINAL ASSEMBLY

4a. Assemble the enclosure

After you have 3D printed the enclosure and bracket, you can create a hinge by adding a #8 machine screw into the holes (Figure Z). This will allow you to adjust the angle of the solar panel for your lighting situation.

4b. Install the electronics

Slide the solar engine board into the end of the enclosure, with the large capacitors going in first (Figure Aa).

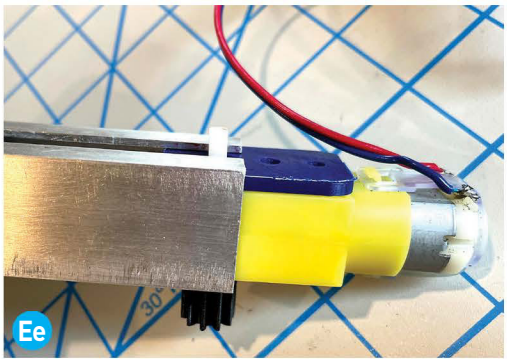
Then slide the solar cell into the rails and over the board, carefully tucking the wires under it (Figure Bb).

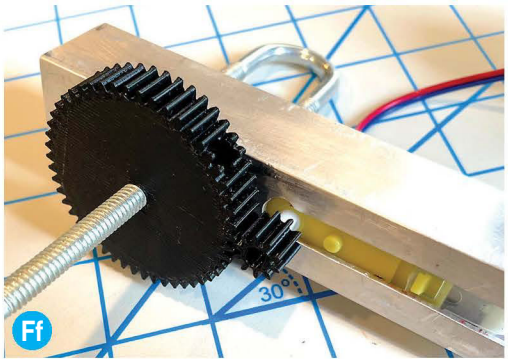
Finally, install the enclosure end cap, making sure the motor wire goes through the hole in it (Figure Cc). It should be snug enough in the rails that it does not need to be glued.

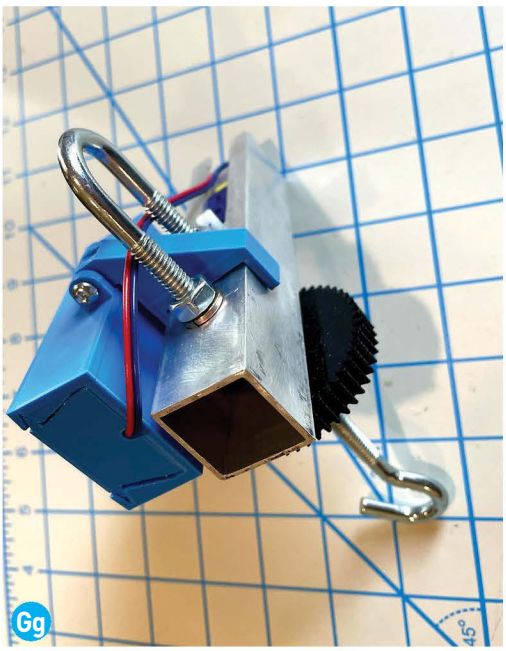
4c. Install the motor

If your TT motor has a loop on the end, snip that off with a pair of edge cutters (Figure Dd). Put the small plastic shim you printed on top of the motor. It should match up with the holes and tab. Push the small gear onto the motor.

Slide the motor into the tube with the shim on









top (Figures Ee and Ff). The shim should keep the motor tightly pressed to the gear side of the tube and be very snug and hard to move out. If it is loose and can slide out on its own, there's a small screw hole on the shim where you can add a short #8 screw to tighten it. You may also need to wrap electrical tape over the motor contacts if they touch the tube.

4d. Assemble enclosure and tube

Finally, clip the enclosure onto the tube between the U-bolt legs (Figure Gg). Optionally add the 3D-printed tube end caps.

Congratulations — you're all done!

PERPETUAL PLANT PIROUETTE

With your new solar plant rotator, you will always have beautiful, happy, healthy houseplants!

Now that you have mastered the Miller solar engine circuit and thrust bearings, you also have some very useful tools in your toolset. Armed with this new knowledge, you could use solar engines to power other projects without the need for batteries or an outlet. Perhaps you'll want to build a playful BEAMbot to entertain guests or annoy your pets.

The hardware you made in this project is also so heavy-duty and robust that it can be used to rotate any heavy items or decorations you might have. If need be, it can be driven by another power source for faster speeds as well.

MORE ON BEAMBOTS

Simple, analog, and autonomous, **BEAM robots** (Biology, Electronics, Aesthetics, and Mechanics) use no batteries and no microcontrollers. Invented in 1989 by Mark W. Tilden (University of Waterloo, Los Alamos National Laboratory, WowWee Toys), they've evolved dozens of species.

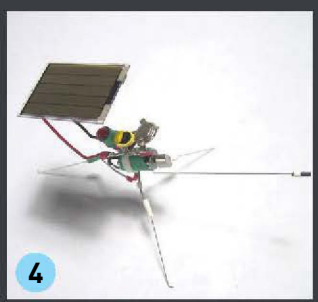
Start with Solarbotics' original guide "BEAM from the Ground Up" (solarbotics.net/bftgu/default.htm) and explore the amazing BEAMbot menageries built by Zach DeBord (fadetofuture.com/2008/12) and Simon Fraser (smfr.org/robots).

Then build these classic *Make:* projects from Gareth Branwyn!





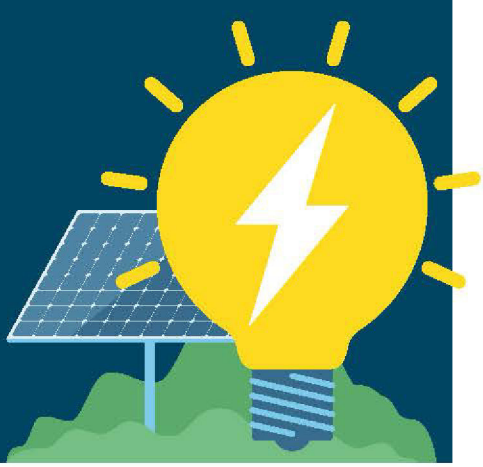




1. **Trimet:** makezine.com/projects/trimet-solar-beam-top
2. **Pummer:** cdn.makezine.com/make/08/pummer.pdf
3. **Solarroller:** makezine.com/projects/solarroller-beam-race-car
4. **Vibrobot:** makezine.com/article/technology/robotics/how-to-build-beam-vibrobots

EXPLORING SOLAR ENGINE DESIGNS

- **FLED (Flashing LED):** A clever circuit that uses a flashing LED as the trigger. instructables.com/Intro_To_BEAM_Robotics_And_The_Solar_Engine
- **CSS555:** We love 555 timer chips and TinkerJim's design using the very efficient CSS555. instructables.com/CSS555-Solar-Engine
- **Easter Engine:** Another design by TinkerJim that uses all discrete components you might have lying around, if you don't want to order a CSS555 or MCP112. instructables.com/The-Easter-Solar-Engine
- **Miller Solarbotics PCB:** Ready-to-use circuit with the 1381 voltage detector. solarbotics.com/wp-content/uploads/miller_solarengine.pdf
- **Miller cardboard version:** Cardboard and copper tape circuit with MCP112, by Wonderful Idea Co. instructables.com/Solar-Engine-Circuit-Boards
- **Many more historical designs:** solarbotics.net/library/circuits/se.html



Douglas Adesko, Zach Debord, Adobe Stock-YummyBuum

Welcome to the Mirrordome

Building an LED sculpture that transforms by night, and is much bigger on the inside

Written and photographed by Lee Wilkins



LEE WILKINS is an artist, cyborg, technologist, and educator based in Montreal, Quebec, a board member of the Open Source Hardware Association, and the author of this column on technology and the body and how they intertwine. Follow them on Instagram @leeborg_

Every winter, Trillium Park on the waterfront in Toronto is lit up with amazing sculptures at night. For a few years now, my friends Kyle Chisholm, Hillary Predko, and Daemon Baliski and I have had the opportunity to create some of these works. This year we're super excited to have made *Greenhouse Reflect*, a mesmerizing mirrored sculpture that changes throughout the cycle of the day, and is my favorite shape, the icosahedron. During the day it's a reflective fragmentation of the landscape, and at night it's a warm, kaleidoscopic greenhouse in the winterscape.

The 12-foot sculpture is made out of two-way mirrors and wooden supports. Two-way mirrors are either transparent or mirrored, depending on which way the light is coming from. It's kind of hard to explain, but if you imagine an office building in a big city that's reflecting the sky during the day, but you can see inside at night, it's the same kind of material. What I love about it is that we can control the effect by putting LEDs inside the sculpture, and letting the sun and moon do the rest!

As a result, when you're standing inside the sculpture during the day you can see the entire landscape outside, and everyone viewing from outside can see the landscape reflected in the exterior. At night, standing inside the sculpture creates an amazing kaleidoscope, and outside people can watch you ogle the effect! I personally do a variety of related works, like my piece *VOID* that uses a similar shape and materials to invite people to put their heads inside the sculpture. This was an extension of that line of work, but it wouldn't have been possible without collaborating with Hillary, Kyle, and Daemon to make it so big and awesome!

TIME REQUIRED: Weeks

DIFFICULTY: Difficult

COST: $5,000

MATERIALS

- **2×4 lumber**
- **Plywood**
- **Two-way mirror, acrylic, 3mm**
- **PVC pipe**
- **Arduino Uno microcontroller**
- **RTC clock module**
- **Weatherproof box** for electronics
- **RGB LED strips, 24V**
- **Concrete**
- **Steel poles**
- **Geodesic dome connector plates, 5-way**
- **Various fastenings: hex bolts, washers, lock nuts, etc.**

TOOLS

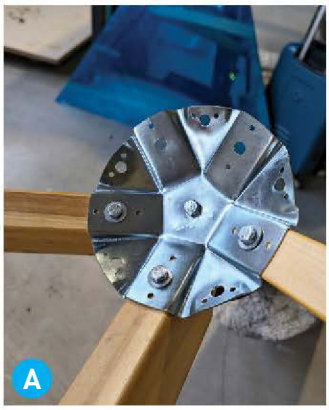
- **3D printer**
- **Chop saw**
- **Laser cutter** we used a cutting service
- **Computer with FreeCAD** design software
- **Wire cutters / snippers**
- **Soldering iron**
- **Socket driver** for bolts

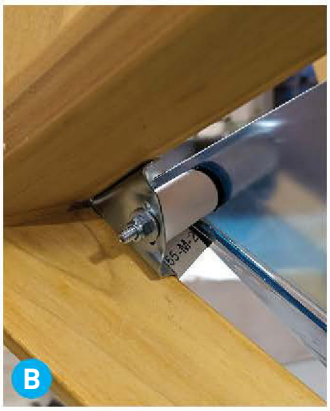
GOOD BIG ART

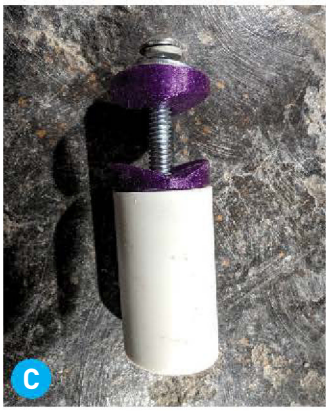
There are a number of considerations when making public art: It has to be sturdy, instructions should be clear, and it should be viewable at all times of day. Making this sculpture sturdy was an issue we were concerned about from the beginning. We knew it would be on uneven ground, on the Toronto waterfront which can get pretty windy, and it had to last 3 months in the Canadian winter. While part of me wanted to see the giant shape rolling across frozen Lake Ontario, we knew that would be frowned upon. We used concrete feet on the bottom of steel posts to hold it in place, along with large bolts to secure each facet.

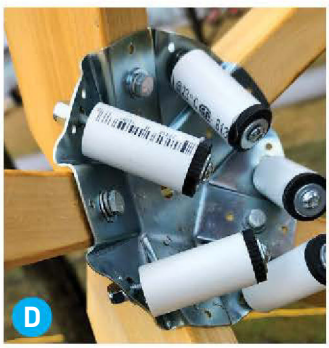
As with any good big art, we also wanted it to be able to have another life — to be stored and reassembled after the show was done. We were lucky enough to have it shown again at another festival, and hopefully more are on the horizon. Each panel and truss comes apart, and remarkably it can fit inside a small hatchback! With the use of threaded inserts, it's easy to set it up again without a fuss, and taking it down is quick too. The only annoying part is the concrete feet, but luckily there are only three.

Another concern we had was how the public would treat the sculpture. Because of cost limitations, the acrylic mirror panels are only 3mm thick. We had a few people try to climb inside the structure and unfortunately some panels did break, but they were easy to swap out (even if they weren't cheap).


A


B


C


D


E


F

GEODESIC AND KALEIDOSCOPIC

To avoid reinventing the wheel, we purchased some pre-made geodesic dome brackets for the corners (Figure A). By getting two sets of dome brackets, we had enough to make a full sphere. We removed one truss in order to let people walk or roll inside with ease, and installed LED lights around the entrance.

The electronics are quite simple; the only catch was that we wanted the light pattern to change throughout the day. We used a ***real-time clock (RTC)*** Arduino module. It was my first time using one of these, and it was pretty simple. The device has a small battery so it's powered at all times. You can select time zones and set the current date, and the RTC does the rest to keep track of time. I set the LEDs to a warm yellow at night, and a cool purple during the daytime, with some transition in the middle.

In order to make the interior mirror effect as immersive as possible, we used interior standoffs to hold the mirror panels away from the skeleton to ensure a close panel fit (Figure B). These we made out of PVC pipes, long bolts, and 3D-printed parts that helped distribute the pressure (Figure C) on the panels. There were also supports along the edges of the structure to stop the panels from sagging and ruining the mirror effect (Figure D).

We all worked very hard on every part, but Daemon was the real genius on the lumber and finishing, Kyle modeled and designed it all using FreeCAD, and Hillary was the glue and hands to make it all into reality. My focus was the mirror effect and electronics. It's such a joy to collaborate on ideas with amazing people.

1. CONCEPT, MODEL AND BOM

We began by reviewing the call for proposals and coming up with an idea. Before a project is funded, we start with a quick Photoshop mockup and general technical discussion. If it gets funded, then we start on the CAD. Figures E and F shows our initial mockups, trying to convey the concept to the panel of judges.

Once the design was approved, we were asked to make it a bit more accessible. We added struts to raise it so that anyone can walk or roll

freely into the structure. Kyle created these amazing CAD drawings using FreeCAD that let us understand how to put it together (Figures G, H, and I). He imported the existing corner brackets and calculated the measurements so we could get a feel for it.

Once we were happy with how it looked, we chose the right hardware and placed a McMaster-Carr order.

2. CUT AND PREP PARTS

Based on the CAD drawings we then cut all the wood to plan (Figure J) and had the mirror panels manufactured by a local laser cutting service. To get a nice corner on the sculpture, we cut the truss corners to about 58 degrees so they would all come together in a flat point (Figure K). We drilled the holes, stained the trusses, and added threaded inserts (Figure L).

Next, we 3D printed a ton of custom brackets. There were two kinds: one for the corners and another to hold up the mirror panels in the center of the truss. Each was made from a long bolt, a large washer, 3D-printed parts, and a large nut. We presorted all the hardware so we didn't have to do it all on site in the middle of winter!

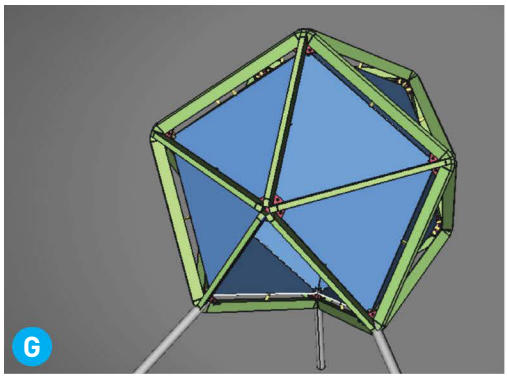
3. CONCRETE FEET

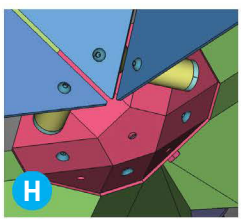
We used concrete blocks to make sure the structure was stable. One key element was to cast them at an angle that would let them stand properly. We used concrete casting forms that were cut on the right angle, and placed the steel poles for the legs inside them (Figure M).

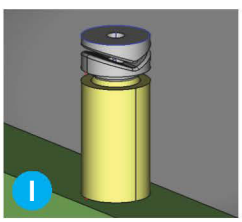
The legs were attached to the flat face of the bottom brackets using a bolt (Figures N and O on the following page). Honestly, we aren't too thrilled with the legs and have a few ideas how to improve them. Other than these huge concrete blocks, it's very easy to assemble and move around, so for future iterations we're considering more traditional weights.

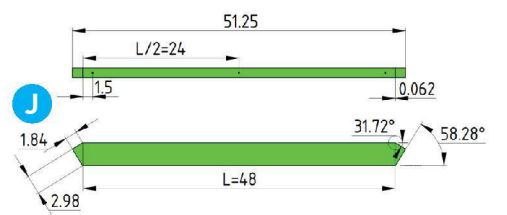
4. ELECTRONICS AND LEDS

The electronics had to be assembled in a weatherproof box (Figure P on the following page). We used a power supply that could output both 24V for the LEDs and 5V for the Arduino, and the RTC had its own battery. RGB LED strips were







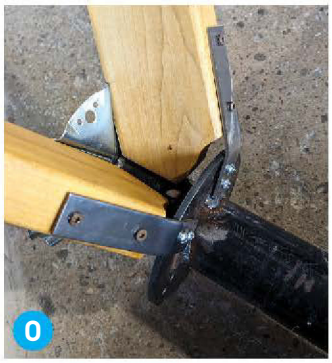


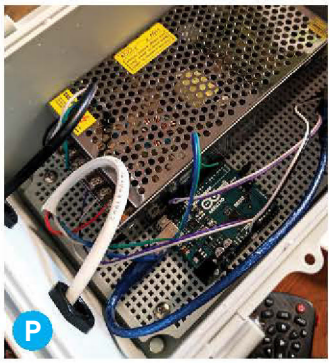









O


P


Q


R


S


T

attached around the entrance triangle (Figure Q).

We used FastLED's **blend** function to transition smoothly from one color to another. It's a very useful tool but doesn't always behave as expected. Just to take a quick sidebar into LED color theory, there are two ways to translate between colors. The first is to move along ***hue***, which will adjust the color along the color wheel to get where you want. For example, going from pink to purple has to go through red. The other way is to ***blend*** by fading each RGB value to the target value; but often there is a white or unpredictable color in the middle that can feel kinda random. In the end, it wasn't a huge deal because the change took place over a period of 1 hour as the sun was setting.

```
  DateTime now = rtc.now();
  int currentHour = now.hour();
  if (currentHour < sunset && currentHour >
sunrise) {
    animation(blend(CRGB(100, 90, 5),
CRGB(100, 50, 255), 0), 10, 10, 50);
  } else if (currentHour > sunset ||
currentHour < sunrise) {
    animation(blend(CRGB(100, 90, 5),
CRGB(100, 50, 255), 255), 10, 10, 50);
  } else if (currentHour == sunrise) {
    int currentMin = now.minute();
    animation(blend(CRGB(100, 90, 5),
CRGB(100, 50, 255), map(currentMin, 0, 60,
0, 255)), 10, 10, 50);
  } else if (currentHour == sunset) {
    int currentMin = now.minute();
    animation(blend(CRGB(100, 90, 5),
CRGB(100, 50, 255), map(currentMin, 0, 60,
255, 0)), 10, 10, 50);
  }
}
```

5. TEST RUN

To be sure it was all working, we did a full test run inside (Figure R) — a good thing, as we found we had to drill out some inserts to be deep enough.

6. FINAL INSTALL

Surprisingly it went together seamlessly (Figure S), but we didn't anticipate how trippy it would be to install! For the test, we had left the protective coating on the mirrors, so we hadn't seen how reflective they'd be. On this overcast day they were in a middle state, both transparent and reflective (Figure T). We had to take turns being inside doing the assembly! We had so much fun making this. I hope you learned something too.

Smart Plant

Ever wondered what secrets our leafy companions hold? Help them spill the beans!

Written and photographed by Jon García Aguado



JON G. AGUADO is a Spanish aerospace engineer living and working in Austria. He is an active enthusiast of self-made gadgets that can make his life easier. He'd love to receive feedback on any of his available boards @jgaguado

Until recently, I relied on the Xiaomi Mi Flora to monitor my indoor plants. While it provided useful plant care info, it had some interface limitations, requiring their specific app for configuration. One day, I noticed some missing data and suspected the battery had died. However, upon searching for the sensor, it was nowhere to be found.

I organized a search party that morning and, after gathering clues and speaking to witnesses, discovered that a neighborhood raven had taken the gadget for its collection of stolen items.

This incident inspired my next project, the Smart Plant — an open source plant monitor with Wi-Fi connectivity that also displays data directly on the board. Here I'll show how you can solder my through-hole prototype. If you like it you can go full SMT with my latest version or buy one on Elecrow to play with.

TIME REQUIRED: A Weekend

DIFFICULTY: Intermediate

COST: $30–$45

MATERIALS

- **Development board with microcontroller and e-paper** like the T5-2.13" ESP32 module from LilyGo (formerly TTGO). You'll also need the male and female headers so you can remove the module as needed.
- **Double sided protoboard, 1.97"×2.76"**
- **Hookup wire**
- **Light sensor** digital like the VEML7700 or MAX44009, or analog like photoresistors (LDR)
- **Air temperature (and humidity) sensors** digital like the AHT20 or the BMP280, or analog like thermoresistors (NTC)
- **LiPo battery, 1000mAh**
- **Capacitive soil moisture sensor**

TOOLS

- **Computer**
- **USB cable**
- **Soldering iron and solder**
- **3D printer**
- **Multimeter (optional)** recommended for checking your soldering

1. COMPONENT SELECTION

For my prototypes, prioritizing low power consumption and my fondness for e-paper displays, I opted for LilyGo's T5 2.13" e-ink development board. This board features an ESP32 with Wi-Fi and Bluetooth capabilities, a 2.13" e-paper display, and essential circuitry for battery charging and protection, among other functionality.

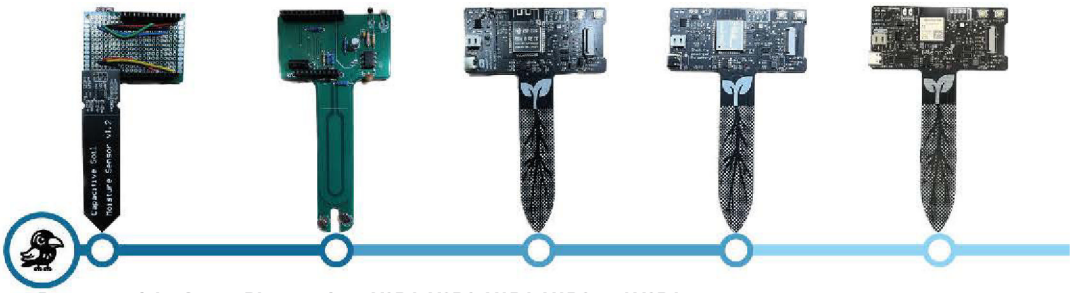
Next, I chose the sensors for measuring my plants' vital parameters. With the intention of simplifying the assembly process by mounting everything on a protoboard and minimizing complexity, I opted for digital sensors. This decision meant I only needed to solder a maximum of four pins (I²C bus + power), with the convenience of receiving measurements in physical units.

My primary criterion was to select sensors that had already been tested and proven compatible with the ESPHome framework. For the light sensor, I selected the Maxim MAX44009, conveniently available on a compact purple module called GY-49. And for the temperature sensor, I repurposed an old GY-BM module containing a Bosch BMP280, which not only measures temperature with an accuracy of ±1.0°C but also provides barometric pressure readings.



Dall-E 3 (Bing Image Creator)

AI-generated sketch of the suspected thief at the crime scene.



Progress of the Smart Plant project: V0R1, V0R2, V1R1, V1R2 and V2R1.

Lastly, I chose a standard capacitive soil moisture sensor board with a simple 3-pin interface (GND, VCC, and AOUT). Although the output is analog, I planned to calibrate it as needed.

In the initial design revision, one sacrifice I had to make was omitting the measurement of soil fertility, which relies on soil electrical conductivity (EC) and necessitates adding corrosive-resistant pads to the PCB.

2.ASSEMBLY

With all the materials prepared for assembly, you'll begin by positioning them on the prototype board as depicted in Figure A.

The LilyGo module is not mounted directly on the protoboard; instead you'll use the female headers shown in Figure B.

In this position, the components will be almost aligned, so you'll have fewer, and shorter, wires to solder.

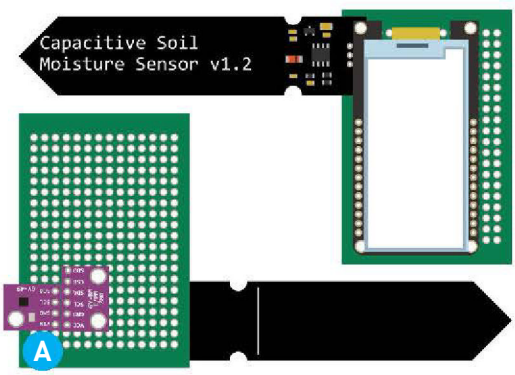
3. SOLDERING

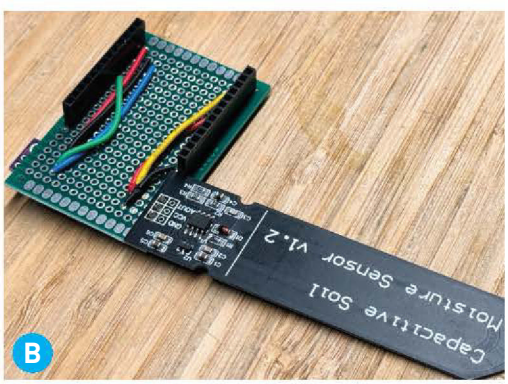
With all the components in position, proceed with soldering the connections between the pins and wires according to the Pinout Table.

Since the GY-49 and GY-BM modules have their 4 pins aligned, I decided to stack them and solder them together (Figure C on the following page).

After you solder all the components and connections, I highly recommend that you check your connections with a multimeter. This way you make sure there are no short circuits that can damage the LilyGo T5 ESP32 module, and you can verify the continuity of your connections to avoid hardware errors.

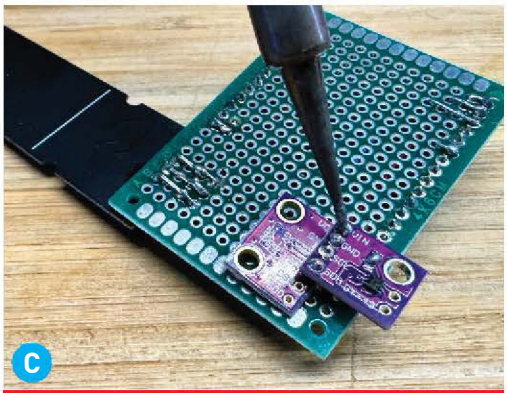
NOTE: Some capacitive soil moisture sensors are poorly designed and may even replace important components with inferior parts to be cheaper. This might result in shorter lifespans and/or wrong measurements.





PINOUT TABLE

ESP32	Soil sensor	GY-49	GY-BM
3V3	VCC	VIN	VCC
GND	GND	GND	GND
GPIO 21		SDA	SDA
GPIO 22		SCL	SCL
GPIO 36	AOUT		



C

CAUTION: Always solder in safe environments, paying special attention to ensure that smoke does not drift into your eyes or lungs, and be mindful of the hot parts you've recently soldered.

```
i2c:
  sda: 21
  scl: 22

spi:
  clk_pin: 18
  mosi_pin: 23

sensor:
  - platform: max44009
    id: light
  - platform: bmp280
    address: 0x76
  - platform: adc
    pin: 36
    id : soil
    unit_of_measurement: "%"
    attenuation: 11db
    filters:
    - calibrate_linear:
        - 1.25 -> 100.00
        - 2.8 -> 0.00
display:
  - platform: waveshare_epaper
    cs_pin: 5
    dc_pin: 27
    busy_pin: 4
    reset_pin: 16
    model: 2.13in-ttgo-bt74
    update_interval: 30s
    full_update_every: 30
    rotation: 270
```

D

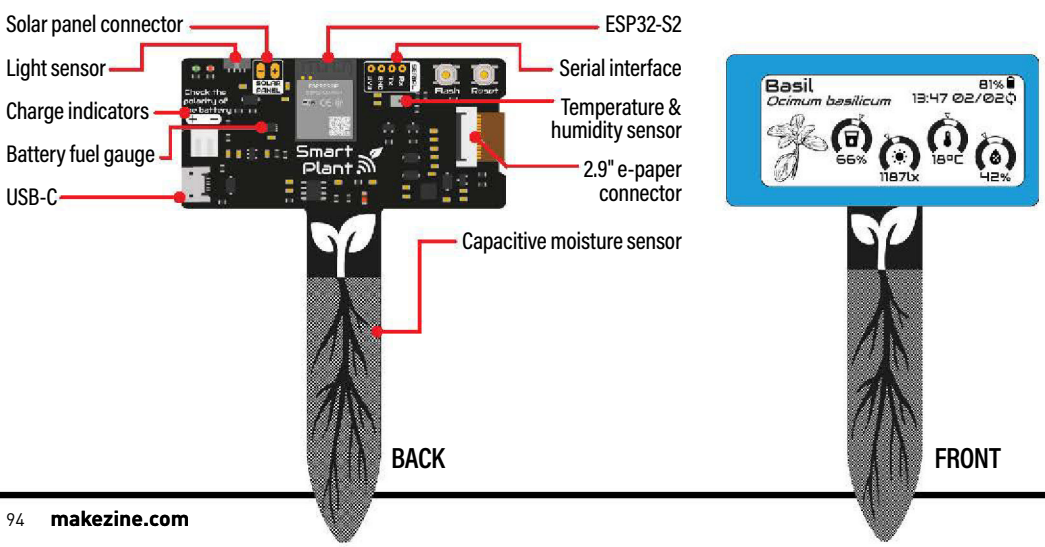
4. PROGRAMMING

With all the hardware assembled, you can proceed with programming the ESP32. While Arduino is a common choice, for this project I've opted for ESPHome (esphome.io), a firmware that's powerful and easy to configure for home automation projects. One of its standout features is its seamless integration and direct communication with Home Assistant (home-assistant.io). Since all the selected sensor modules are directly supported as Sensor Components on ESPHome, the configuration YAML file looks similar to Figure D.

After you flash the LilyGo with the ESPHome firmware, calibrating the soil moisture sensor is necessary. This can be achieved by inserting the probe into soils representing 0% and 100% moisture levels, then noting the corresponding readings. This data allows for later application of a linear calibration.

GOING FURTHER WITH THE HARDWARE

After multiple iterations and extensive testing of sensors, I've reached Smart Plant version V2R1, which embodies numerous lessons learned. Key enhancements include digital sensors compatible with deep-sleep mode, battery charging and monitoring capabilities, support for a solar panel, and a layout conducive to a two-part 3D printed case. You can get the 3D files, PCB files, and schematics at smart-plant.readthedocs.io.



DAILY USAGE

One of the most valuable features of the Smart Plant is its ability to display data not only numerically but also with gauge indicators referencing recommended ranges. To obtain these indicators I automated the background generation (with the gauges, ranges, plant names and sketches) through a Python script and ChatGPT.

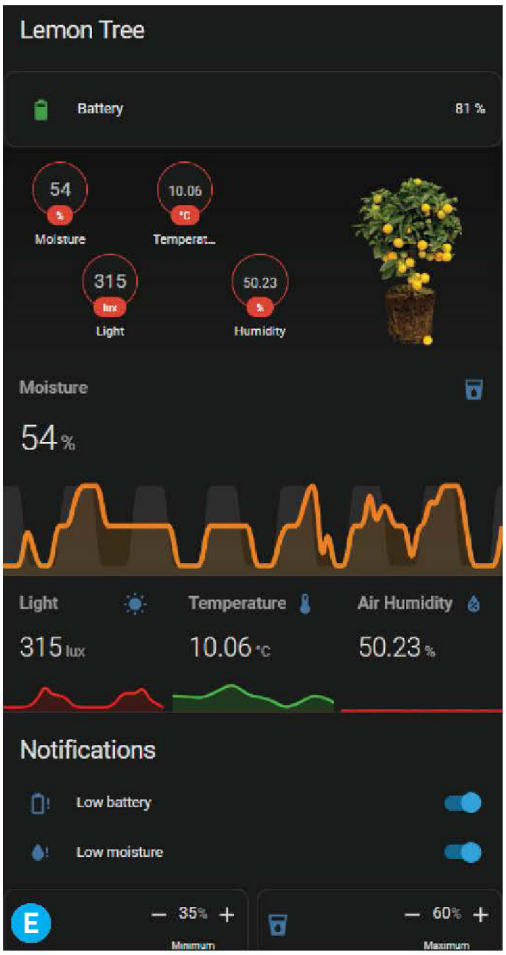
Furthermore, ESPHome can be customized to display messages based on various scenarios, such as time or parameters exceeding recommended values.

The seamless integration of ESPHome-flashed devices with Home Assistant simplifies the creation of dashboard cards like the one depicted in Figure E. This enables me to remotely monitor the plant's status via a web browser or smartphone.

During the summer, some plants outside on the balcony benefit from an automated irrigation system. This system waters them based on each plant's actual needs and the weather forecast, thereby reducing water waste and ensuring optimal plant care.

After all, perhaps that raven was just a silent guardian, a watchful protector. A dark knight that simply wanted to help me improve my plants' well-being.

If you found this project interesting and want to dive deeper into the documentation, visit: *smart-plant.readthedocs.io*







DIY Tortilla Press

Build a traditional taco substrate squasher — for a few centavos!

Written and photographed by Brookelynn Morris



There is an unparalleled joy in the making of things that have the purpose of making other things. Think of the satisfaction of making a jig to bend wire for a project, or the pride in making a tool to complete a difficult task. And then there is a specific delight in making something that can be used to make food.

One of the most delicious foods I've ever eaten was a fresh tortilla made and cooked by my mother-in-law Amelia from Mexico City. The entire kitchen had been transformed for a massive tortilla production event, and at the center was a humble tortilla press. My father-in-law Gabriel made it years ago and it has been producing fantastic tortillas since.

Taking a look at the press, it is evident how to use it. And with a few photos and simple steps, I am thrilled to teach you how to make your own tortilla press. The best part — you can make your own incredible tortillas with it for years and generations to come.

This tortilla press uses scrap wood and reclaimed hardware. Because the tortillas will be made in between heavy layers of plastic, the surface of the wood needs to be smooth and flat, but it can be left raw, or stained and painted.

The construction of the press is simple. You'll need two hinges, some screws and nails, a 6" bolt with washer and wing nut, two matching boards for the top and bottom of the press, a handle, a U-shaped board to hold the handle, and a scrap of wood to help create pressure through leverage. Ours has feet, but they're not necessary.

1. CUT THE WOOD

Our two plates for the press measure 9"×12", 1¾" thick. Our U-shaped fulcrum block is 5½" square, 1¾" thick, with a space cut out from the middle that measures 3" long and 1¾" across. The handle itself is 15" long and just wide enough to fit inside the U to rotate freely: 1½" wide. The small leverage block attached to the top plate of the press is 3"×2½", and about ½" thick.

2. ASSEMBLE THE PLATES

After cutting the wooden pieces, assembly is quite simple.

Use short nails or screws to secure the small leverage piece to the center of the top plate, ¼"

TIME REQUIRED: 1–2 Hours

DIFFICULTY: Easy

COST: $0–$10

MATERIALS

- **Wood boards, 1¾" thick: 9"×12" (2), 5½"×5½" (1), and 15"×1½" (1)** Hard or semi-hard woods will be tougher and last longer, but softwoods work too.
- **Wood scrap, about ½" thick** for the pressure bar
- **Hinges (2)** to fit your boards
- **Wood screws** to fit your hinges
- **Nails or wood screws** about 1" long to mount scrap block to top plate, and about 3" long to mount fulcrum block to bottom plate
- **Bolt, ¼"×6", with washers and wing nut**

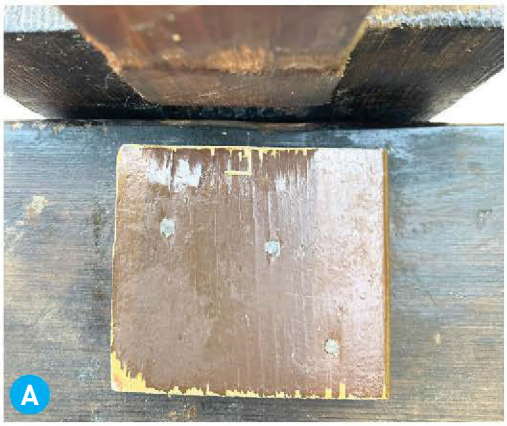
TOOLS

- **Hand saw**
- **Drill**
- **Hammer**
- **Screwdriver or driver bit for drill**



BROOKELYNN MORRIS wrote her first piece for *Make:*'s former sister magazine *Craft* 17 years ago. She instantly fell in love with all the eccentrics in the vibrant community of people who make things.

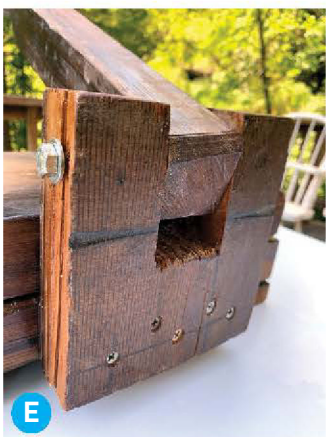



A


B


C


D


E


F


G

from the 12" edge (Figure A).

Stack the two plates of the press together, line them up nicely, and then connect them together with the hinges — on the edge opposite the leverage block (Figure B) — so they open like a book (Figure C).

3. ASSEMBLE THE HANDLE

Drill a small hole for the bolt through both arms of the U-shaped fulcrum block, centered 1" from the top of the U.

Drill a hole through the center of the handle — ours is about 1" from the end of the handle. Make sure there's plenty of clearance. Use washers and a wing nut to bolt the handle into the block, loose enough for the handle to swing freely (Figure D).

With screws or nails, mount the handle-and-block assembly, centered, to the edge of the bottom plate (Figure E).

If you want, now you can attach the feet to the bottom of the bottom plate as well. We used more wood scraps.

TORTILLA TIME

To use the press, close the plates together and then bring the handle down, applying pressure to the leverage point (Figures F and G).

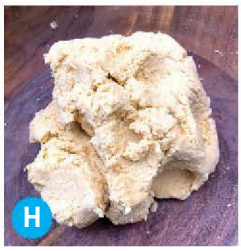
To make the best possible tortilla, center the ball of dough between two sheets of wax paper or plastic. Ours are cut from a heavy-duty zip-lock bag. Close the press and apply a few seconds of steady, even pressure to flatten the masa. The bigger the ball, the wider and thicker the final tortilla.

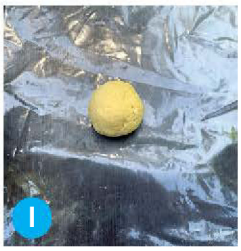
The masa dough is very simple to make. Add 1½ cups of water to 2 cups of masa harina and ½ teaspoon of salt. If the dough is a little too dry, add water a tablespoon at a time. The goal is to achieve a texture like wet sand (Figure H).

Roll the dough into 1" balls (Figure I) and press away (Figure J).

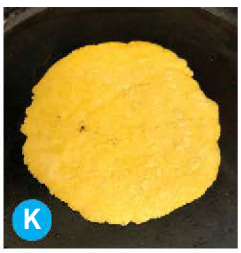
Cook the pressed tortillas on a pan or a griddle for 90 seconds, flipping the tortilla every 30 seconds (Figures K and L).

Buen provecho!


H


I


J

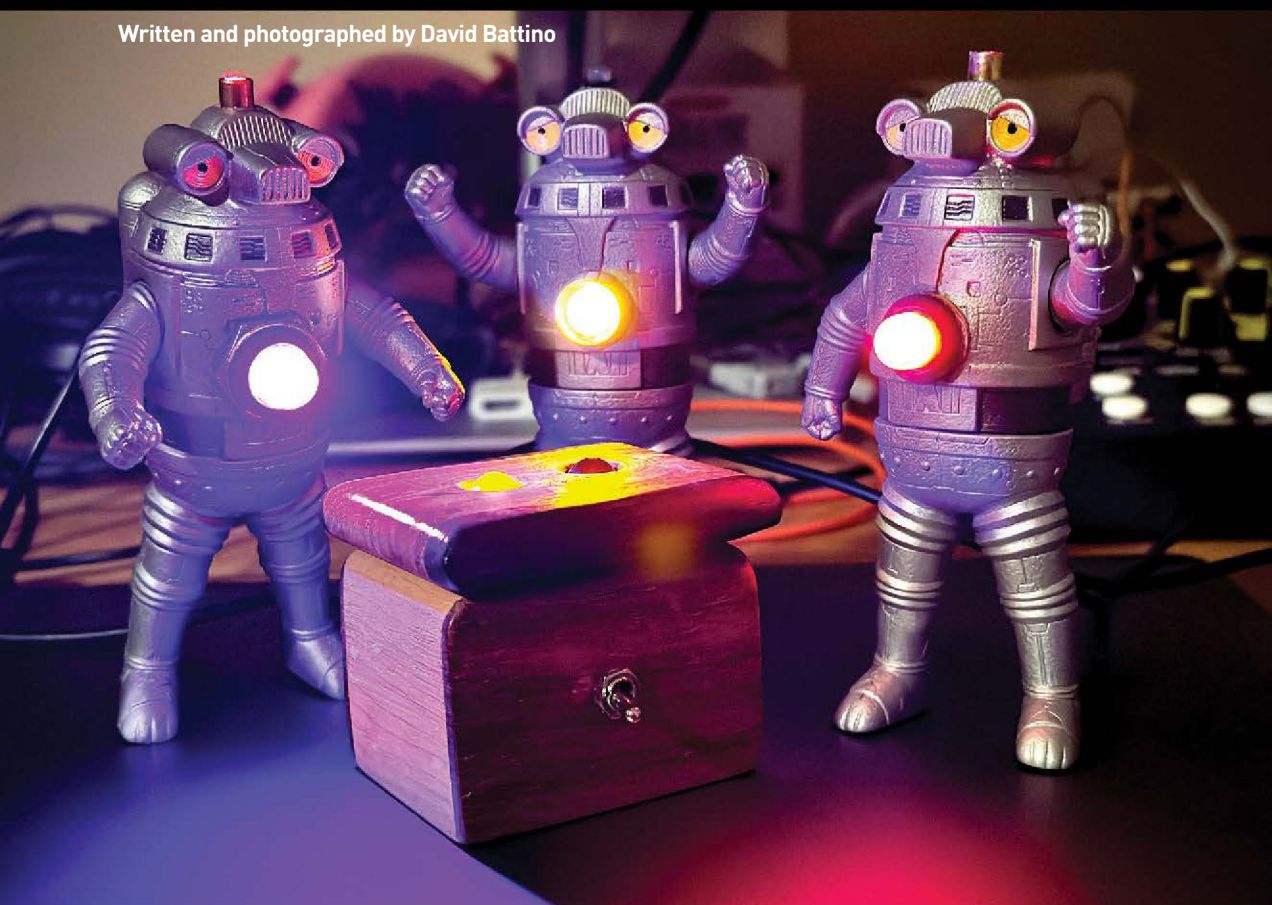

K


L



Guardians of the Cubicle

Written and photographed by David Battino



Turn a toy into a status signal with this simple soldering project



DAVID BATTINO (batmosphere.com) is the co-author of *The Art of Digital Music* and writes the popular "Synth Hacks" column for *Waveform*. With his wife, Hazuki, he also self-publishes Japanese storytelling books, which they have performed at four Maker Faires.

My office had a problem: Our high-walled cubicles and various telework schedules made it difficult to know when someone was at their desk. We'd barge in and interrupt Zoom meetings, or see an empty seat and wonder if the person was coming back soon or working from home. In some companies, hackers build network gadgets that light up to show their Microsoft Teams status (available, away, or busy), but our IT department prohibits networked peripherals. So, I bought a bunch of Japanese action figures and added LEDs, lasers, and a switch. If the light's off, we're teleworking. Red means away or busy, and green means come on in.

1. Choose your character

My team does tech support, so I picked Sevenger, Ultraman's robot sidekick (youtu.be/xx4lwVyvJUc). His hollow vinyl body pulls apart at the waist, revealing plenty of room for electronics. A basic "busy/away" light needs just a red LED, a snap-in socket, a resistor, and a power cord (Figures A and B). Adding a cheap 5V laser isn't much more complicated.

TIME REQUIRED: 1 Hour

DIFFICULTY: Easy

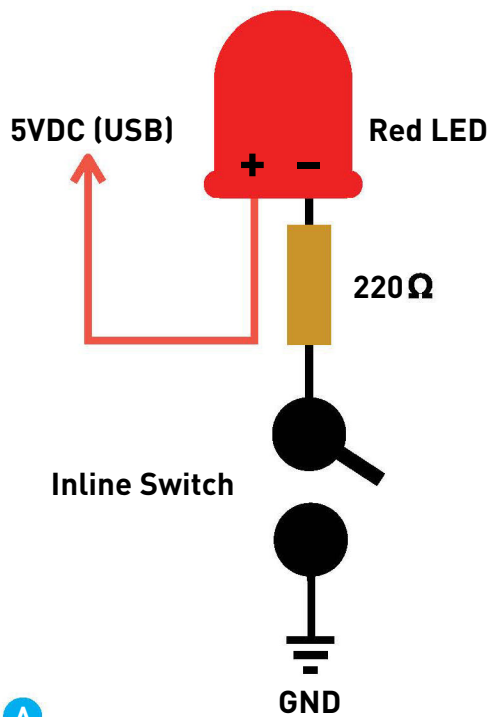
COST: $20

TOOLS:

- **Hollow action figure** like the Bandai Ultra Kaiju series, amazon.com/s?k=bandai+ultra+kaiju
- **LEDs, single color or RGB** I like the large 10mm ones.
- **LED sockets, snap-in**
- **Resistor, 220Ω or larger**
- **On-off switch**
- **USB power cord** like Amazon B09LCTB6LW, B0CL4P2TWP, or B07JGR7JJQ; or cut the end off an old cord
- **Enhancements (optional):** DPDT switch, 5V laser (like Amazon B071FT9HSV), DC power socket, magnets and BBs for stability

TOOLS:

- **Drill**
- **Tapered reamer**
- **X-Acto knife**
- **Soldering iron and solder**
- **Hookup wire, ~24 AWG**
- **Longnose pliers**

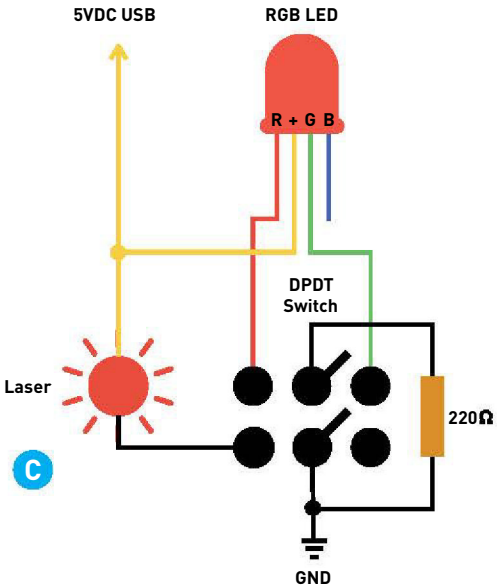


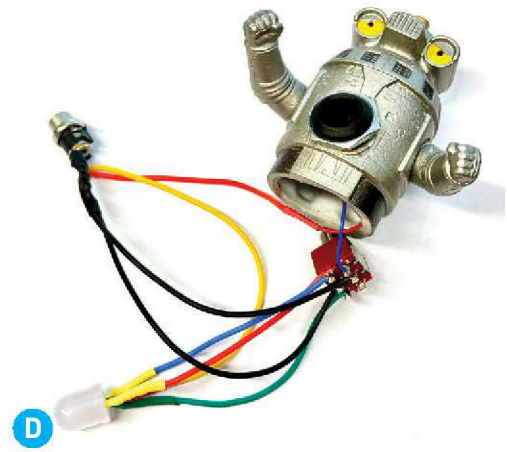
A



B

Adobe Stock-pixaroma





2. Add more light

Add a DPDT switch and a second LED (or use an RGB one) and you can flip between two colors. I also added a tiny laser (Figure C) that blasts the ceiling for even better visibility.

For a teammate who's a Sacramento Kings fan, I soldered red and blue LEDs together, creating a royal purple. Visit batmosphere.com/statusbots to see all these circuits.

3. The boring part

Drilling holes in vinyl action figures is tricky because the material stretches. But with patience, a reamer, and an X-Acto knife for enlarging the holes, you can fit the lights securely (Figure D). Super glue helps if you shave too much.

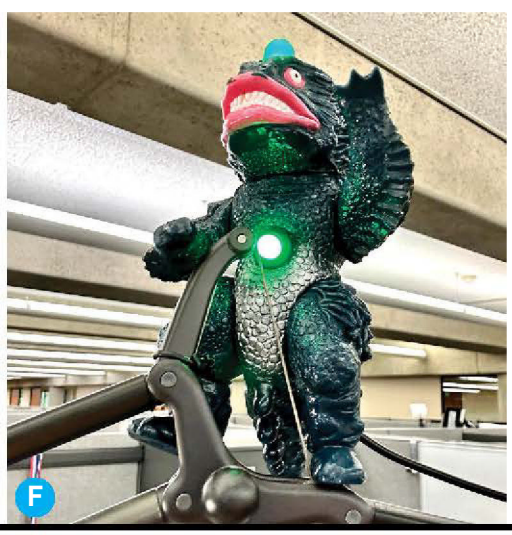
I also drop magnets inside the characters' feet and fill their legs with hot glue and BBs for stability.

Make Light Work for Yourself

As eye-catching as these characters are, your coworkers will still need some initial guidance, especially if you use novel colors. I paired my statusbot with a sign explaining the meaning of my lights (Figure E). Later, I listed my telework days too.

I even built a lizard version (Figure F) with large red, green, and yellow LEDs selected by a three-way guitar pickup switch. But the distinction between yellow (away) and red (busy/away) was too subtle, so now I'm leaning on the lasers again. I wonder how a green laser would look?





Build a PC from Scratch

The old-school tower PC is modular, sustainable — and cool looking!

Written by Carsten Frauenheim



Building personal computers is easier than you think! Whether your friend's gaming rig makes your daily driver feel Neolithic, or you're curious about VR, or you're just looking to get your hands in some computer guts — PC building could be for you. But where do you even start?

In today's vast world of disposable tech, the old-school tower PC still stands strong as the gold standard of modularity and repairability — and its popularity isn't waning. At iFixit, we confidently recommend PCs as a sustainable alternative. Building a computer from scratch —finding affordable parts, navigating what's compatible with what, and handling delicate, expensive components — may feel daunting, but you can do it using only a few screwdrivers.

How much RAM? Which GPU goes with my CPU? Which liquid cooler looks coolest? How do I apply thermal paste? We'll answer common questions, provide tools and resources, and give you the know-how to help you build the PC you've always wanted. Our step-by-step guide is too long to print here — read it at makezine.com/projects/build-a-pc-from-scratch and get started on your dream PC.

TIME REQUIRED: A Weekend

DIFFICULTY: Easy/Moderate

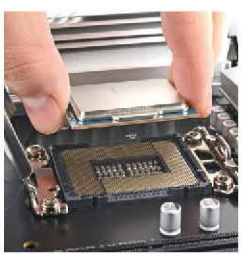
COST: $500–$2,000

PARTS:

- **Motherboard** Mini ITX, Micro ATX, or Standard ATX size
- **Main processor (CPU)** midrange Intel Core i5 or AMD Ryzen 5; high end Core i7 or i9, Ryzen 7 or 9
- **CPU cooler** of your choice
- **Graphics card (GPU) (optional)**
- **System memory (RAM)** DDR4, or DDR5
- **Storage drive, solid state (SSD)**
- **Storage drive, hard disk (HDD) (optional)**
- **Case, tower style** to match your motherboard size
- **Power supply unit (PSU)**
- **Upgrades and bling (optional):** RGB fans, RGB-equipped RAM, PSU cable extensions, sound card, network card, etc.

TOOLS:

- **Screwdrivers, Phillips** magnetic tip recommended







CARSTEN FRAUENHEIM is a Repairability Engineer at iFixit (ifixit.com), where he works with tech companies to make their devices easier to repair. He also enjoys building computers, wrenching on cars, traveling, and hanging out with his wife and cat.

Talking Zombie Doll Maker

Needle-felt these mini zombie dolls — and make them yelp!

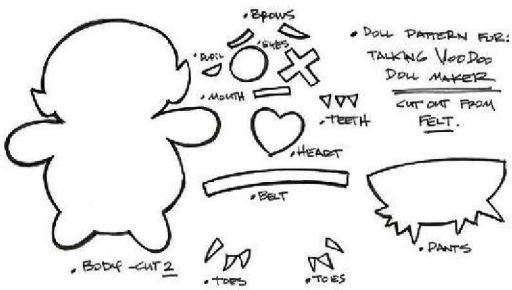
Written and photographed by Bob Knetzger



Adobe Stock-pixaroma

Take your needle felting to a new level this Halloween with this Talking Zombie Doll Maker. Every time you poke the felting needle, the cute mini-zombie doll responds with a funny "Ouch!" and spooky sound effects. The tombstone counter keeps track of the total number of needle strokes as you go. How many pokes to make a monster? Now you'll know!

This graveyard-themed needle felting station has a toyetic look, echoing the classic 1960s movie monster models. Make the entire project, hack the electronic parts, or skip all that and just craft some needle-felted mini zombie dolls — it's up to you!



MAKE IT!

1. BUILD THE HOUSING

I vacuum-formed the parts but you could design your own version using 3D-printed or laser-cut parts, or just fabricate an enclosure from scratch. I chose vacuum forming because it's quick and easy, and the resultant parts are hollow — perfect for housing components. (If you're new to vacuum forming, try my "Kitchen Floor Vacuum Former" project from *Make:* Volume 11 at makezine.com/projects/kitchen-floor-vacuum-former.)

The base and tombstone forms are made from plywood and rigid urethane foam, which is super-easy to cut and shape with hand tools and sandpaper (Figure A). Glue the parts together with PVA glue.

TIP: Remember to make generous ***draft angles*** on all the sides of your forms: that keeps your forms from becoming trapped inside the formed plastic and makes for easy unmolding.

TIME REQUIRED: 6–8 Hours

DIFFICULTY: Easy

COST: $30–$60

MATERIALS

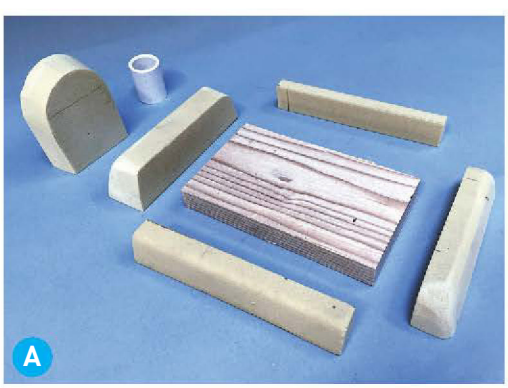
- **Foam, rigid and soft**
- **Plywood**
- **Styrene sheet**
- **Plastic rod and tube**
- **Electronic sound player** Amazon B09838SQ7X
- **Digital tally counter** Amazon B0CJBXRJ3M
- **4-conductor wire** coiled if possible. I wrapped a straight cord around a dowel and left it to take a "set" but an old coiled handset phone cord would also work — it even has four conductors!
- **SPST mini switches**
- **Paint**
- **PVA glue** e.g. white glue, wood glue
- **Wool felt, yarn, and roving** Only wool will work for needle felting, not acrylic.
- **Double stick tape**

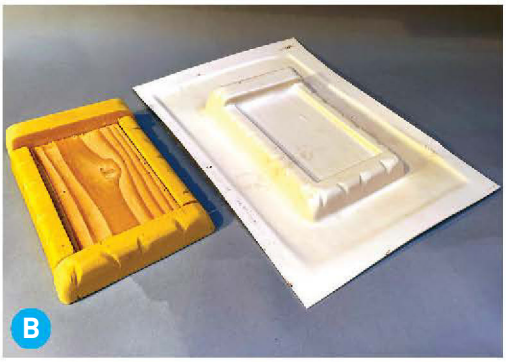
TOOLS

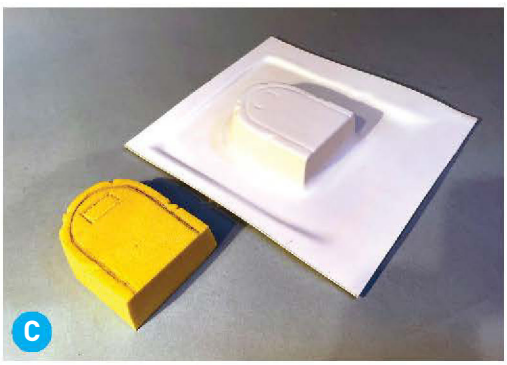
- **Saw and drill** power or hand
- **Sandpaper and files**
- **Vacuum former (optional)**
- **Hobby knife**
- **Rotary tool** e.g. Dremel
- **Felting needle**
- **Hot glue gun**
- **Scissors**
- **Electrostatic flocking gun (optional)**



BOB KNETZGER is a designer/inventor/musician whose award-winning toys have been featured on *The Tonight Show*, *Nightline*, and *Good Morning America*. He is the author of *Make: Fun!*, available at makershed.com and fine bookstores.

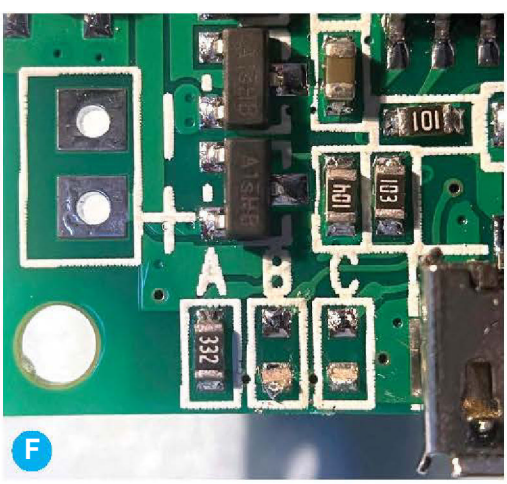












Vacuum-form the parts from styrene sheet (Figures B and C), then trim them and drill two small holes for mounting the tombstone to the base with tiny nuts and bolts (Figure D). I added some small "RIP" plastic letters, cut out the opening for the counter's LCD and reset button, and drilled some speaker grill holes. Use a rotary tool to carve a slot in the back for the wiring (Figure E).

2. HACK THE ELECTRONICS

I found a very versatile sound-playing module online, Amazon B09838SQ7X. It instantly replays a recorded sound from each quick needle poke. If you don't poke again, the sound track continues to play with extended creepy graveyard monster sounds and music.

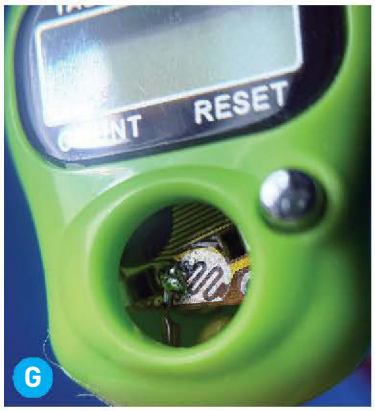
This particular module has user-selectable play modes: leave or remove three surface-mounted resistors (A, B, and C) to configure for one of seven different sound playback modes. For this project I removed resistors B and C, leaving resistor A intact (Figure F). I wired a small SPST switch on the 4-conductor wire to trigger the sound.

TIP: With its long sound-playing time and seven different playback modes, this versatile circuit would be great in lots of other projects!

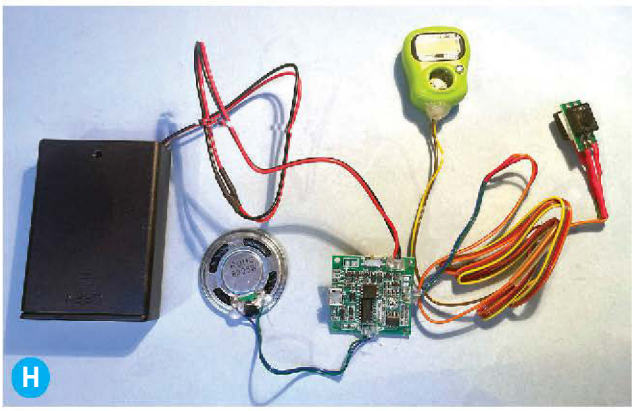
Go online at makezine.com/projects/talking-zombie-doll-maker to download the talking zombie sound effect MP3 file. Follow the included instructions to load your MP3 onto the sound module. It has a couple steps that may vary if you get a slightly different model .

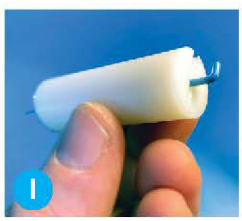
For the counter, I hacked an existing finger tally counter, Amazon B0CJBXRJ3M. It has an LCD display and count / reset buttons. It comes already assembled with a battery — far cheaper than you could ever build from parts!

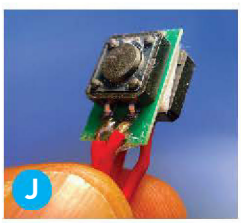
Using the remaining two conductors on the wire, I simply piggy-backed the other small SPST switch to the counter button traces on the circuit board. Remove the big button (Figure G) and carefully reassemble the counter, making sure to position the zebra strip connector for the LCD. Now every time you press the remote wired

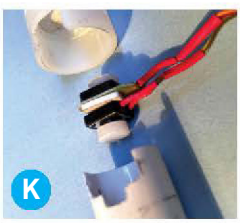


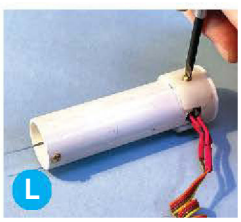
G


H


I


J


K


L

switch, the LCD counter increments.

Figure H shows the completed electronics with battery pack, speaker, sound board, counter module, and wired switches.

3. FABRICATE THE NEEDLE HANDLE / SWITCH

For the needle handle, I turned a cylinder out of Delrin plastic to slide smoothly inside a piece of PVC pipe. I drilled a through-hole in the center to accept the felting needle, then I cut a clearance slot in the end to hold the needle's bent end (Figure I).

The mini pushbutton switches are foam-taped together back to back (Figure J) and positioned inside the pipe, between the end cap and the needle cylinder. Now when the needle is pressed down it slides inside and presses both switches, playing the sound and incrementing the counter.

NOTE: Cut out openings for the wires and add a small screw on the open end of the pipe to prevent the needle from sliding out (Figures K and L).

Now test the handle: Push down the felting needle to trigger both the sound player and counter (Figure M).


M

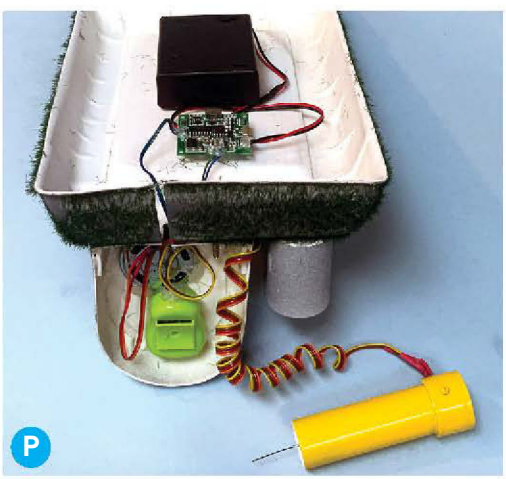
4. PAINT AND FINISH

Prime and paint the plastic parts, being sure to mask off the insides of the needle handle.

TIP: As on any prototype, avoid painting any sliding or bearing surfaces. You'll want smooth action without any sticky paint on them.


N


O


P


Q


R

For a special "grass" look on the base I added flocking. This is commonly used on train layouts and model dioramas. A special tool creates an electrostatic charge that makes the fibers stand up on end.

First, paint the part with water-based white glue or PVA. Then fill the tool's reservoir cup with flocking fibers. Screw on the screened cap, making sure the inside wire contacts the screen. Connect the grounding alligator clip to the glued part.

Press the button to energize the screen and gently shake out the fibers. 3,000 volts of static electricity force the fibers to repel each other — just like static electricity makes your hair stand up! This creates a cool-looking "grass" effect (Figure N).

When you're done, don't forget to carefully touch the alligator clip to the screen to completely discharge the remaining voltage — *ZZZZAP!!*

Let the glue dry completely, then shake off the excess grass.

CAUTION: Be extra careful when using the static gun. Even though the amperage is tiny, the high voltage can give you a BIG shock! Whenever working around high voltages keep one hand in your pocket so that you don't ever create a hand-to-hand path across your heart!

5. FINAL ASSEMBLY

Cut the soft foam to size for your needle-felting pad and glue it into the base (Figure O). I also added a PVC coupler fitting to the base to hold the needle tool.

Mount the battery pack and sound board in the base with double-back foam tape, and hot-glue the counter inside the tombstone so you can see the LCD and work the reset button (Figures P and Q).

Your zombie needle felting station is complete (Figure R).

USE IT!

Have fun making lots of needle-felted crafts with your Talking Zombie Doll Maker, for Halloween or any time.

MAKE A ZOMBIE MINI DOLL

Download the doll pattern online at makezine.com/go/zombie-doll and print it out. Pin it to two stacked pieces of felt. Use scissors to cut out the identical top and bottom doll body parts at the same time (Figures S and T). Also cut out parts for felt eyes, pants, belt, eyebrows, mouth, etc. with different colors of felt.

You can join wool felt parts together without sewing or thread. Just overlap the parts and start poking them with the needle. The barbs on the side of the felting needle pull the fibers to "felt" them together instead of stitching. Additional pokes make a stronger connection. Only wool yarn and felt will work with felting needles. Smooth acrylic yarns and felts do not have the rough scales like on natural fibers that tangle and mat together.

TIP: Use straight pins to hold the felt parts together on the foam temporarily as you poke. Keep your other fingers safely away!

First add the pants, eyes, and other parts to the top doll body (Figures U and V). You can add other touches: needle-felt on pieces of wool yarn to make scars, stitches, monograms, or other fine details. Your zombie will talk as the poke counter tally counts your strokes.

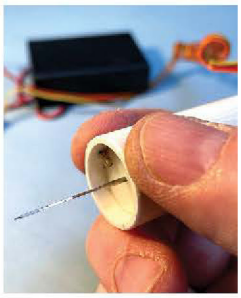
Then place the doll bottom underneath and poke all around the edge of the body. Leave the top of the head open for now.

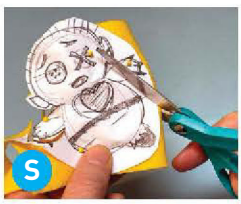
Carefully stuff the body with batting or wool roving. Gently poke the stuffing into the arms and legs using a toothpick or chopstick. If a seam opens up, just go back and poke it again to felt it back together.

Add loose wool roving to make wispy zombie hair (Figure W). Fold the long loose fibers in half and stitch the folded fibers between the top and bottom of the head as you stitch it together. You can poke the loose fibers together to make flat felted patches, blended colors, dreadlocks, etc.

Have a mini zombie doll Halloween party — it's a graveyard smash! R.I.P. — "Rest In Peace?" More like "Repeated Interlocking Pokes!" The tombstone counter shows the total number of pokes you used to make your creation!









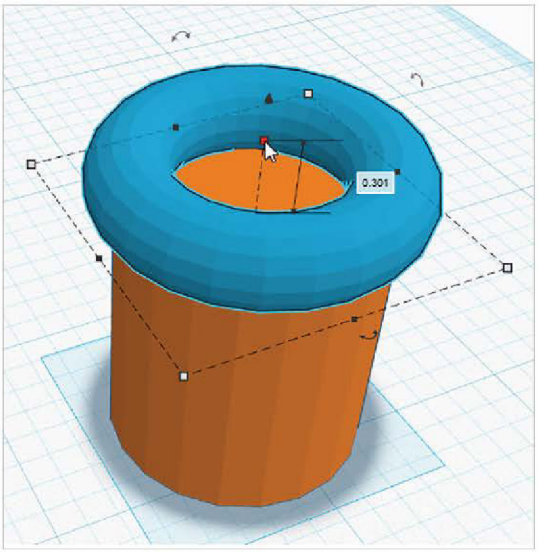


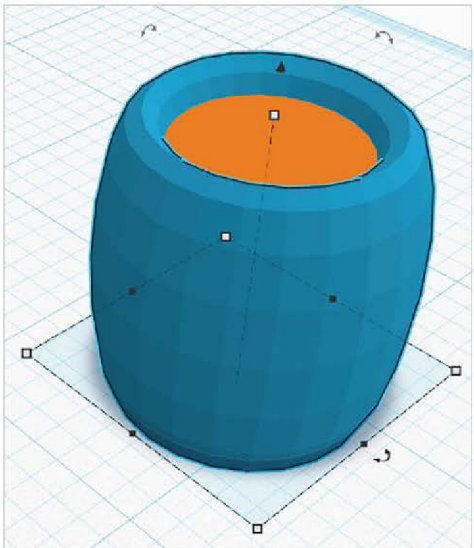












SOLVING DESIGN PROBLEMS WITH CHATGPT

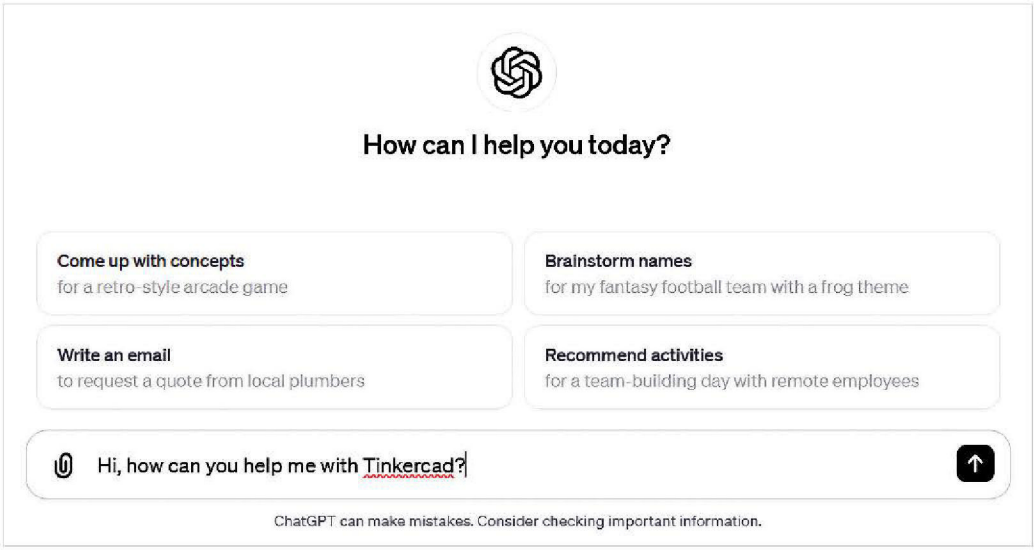
Written by Lydia Sloan Cline



This tutorial is excerpted from the new Make: book ***The Complete Guide to Tinkercad: Design, Sculpt, and 3D Print Your Ideas***, available now at the Maker Shed (makershed.com) and fine booksellers.



LYDIA SLOAN CLINE teaches digital modeling and 3D printing at Johnson County Community College in Overland Park, Kansas, and is the author of *Make: Fusion 360 for Makers*. She is a 3D printing enthusiast and a judge at competitive technology events, and is active in her local Maker community.



A Type questions and get answers from ChatGPT online.

In this brief tutorial we'll discuss ways to incorporate ChatGPT into your design process using Tinkercad, to solve problems around the house.

WHAT IS CHATGPT?

ChatGPT is a Large Language Model (a type of artificial intelligence) developed by OpenAI. It has been trained on extensive amounts of text from books, websites, articles, and other written sources. You can type questions and receive answers in human-like form (Figure A). Check it out at chat.openai.com. As of this writing, ChatGPT-3.5 is free, and ChatGPT-4 is a paid subscription. Your answers will vary from the ones I show here based on the version you use.

The help you'll get depends on the ***prompts*** (questions) you ask. You need to be precise; as with an internet search, different questions get different responses. As of this writing, ChatGPT-3.5 hasn't been trained on any data past January 2022, so it can't help with more recent information. Its answers may be too brief or too involved for your liking, but as long as that answer contains the one nugget you need to work through your problem, it serves its purpose. Take from a ChatGPT conversation what works for you. Use what makes sense, figure out what doesn't, or follow the generated instructions as a guide.

HOW CAN I USE CHATGPT WITH TINKERCAD?

Here are some ways you can incorporate this tool with Tinkercad:

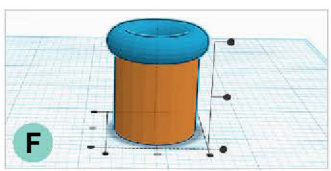
- **Brainstorming** Hold a discussion with it to produce ideas and solve problems.
- **Instructions and Design Tips** It can tell you how to get started, how to use shapes, Group, and other tools, and how to make simple things. Some instructions may be unclear; it takes some prompting, and you might not get an answer that is satisfactory for you.
- **Troubleshooting** It can help diagnose trouble and suggest potential solutions.
- **Educational Resources** It can find online resources, tutorials, and communities that might help you.
- **Research Assistance** It can find answers to questions, draft surveys, and questionnaires.
- **Promotional Materials** It can create educational and informational content, and even images (with paid subscription). Again, figure out what makes sense and what doesn't.



B


C


E


F


G

To make a barrel shape in Tinkercad, follow these steps:

1. **Add the Base Cylinder:**
   - Select the "Cylinder" shape from the basic shapes menu and drag it onto the workplane.
   - Adjust the height and diameter of the cylinder to fit the size of the barrel you want. This will be the central part of the barrel.
2. **Create the Middle Bulge:**
   - Duplicate the base cylinder by selecting it and pressing `Ctrl+D`.
   - Increase the diameter of the duplicated cylinder slightly to create a bulge.
   - Reduce the height of this bulging cylinder so that it forms the middle part of the barrel.
   - Position the bulging cylinder in the center of the base cylinder.
3. **Create the Tapered Ends:**
   - Duplicate the base cylinder again and reduce its diameter slightly to create the tapered ends.
   - Reduce the height of the duplicated cylinder so that it forms one end of the barrel.
   - Position this smaller cylinder on top of the bulging middle part, aligning it with the center.
   - Duplicate this smaller cylinder and move the copy to the bottom of the bulging middle part, aligning it with the center.

D

PROJECT:
HANDLE FOR MECHANICAL BANK LEVER

Figure B shows a vintage coin bank. **The Problem:** At one time the metal lever had a rubber handle, but that handle somehow disappeared, making the lever both unaesthetic and uncomfortable to use. Let's make a replacement handle using the image in Figure C as a guide.

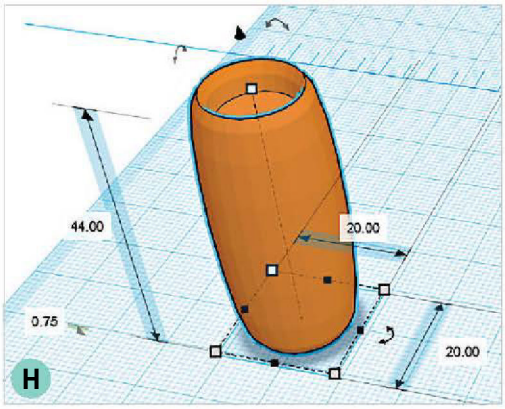
Figure D shows one iteration of ChatGPT instructions. Regenerating the question results in a different solution. I regenerated it several times, and often the solutions were too involved for my liking. But I did get some insight on how to easily make a barrel using a ***cylinder*** and ***torus***:

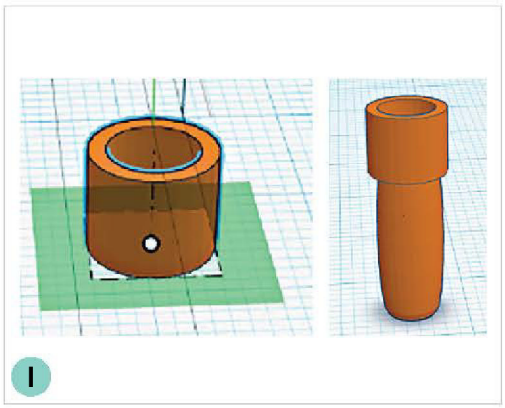
1. Use a caliper to measure the lever's thickness (Figure E). It's 1.98mm, so we'll use 2mm to give room for clearance. We'll make the handle 44mm×20mm×20mm.

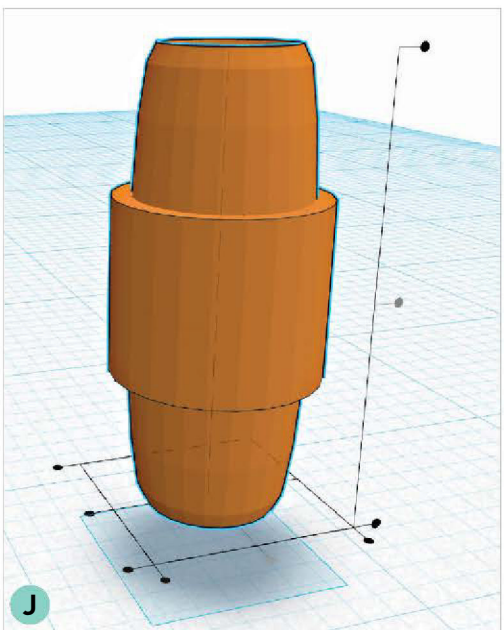
2. Drag a cylinder into the workspace and stack a torus on it. Select them both, click the Align tool, and align their centers (Figure F).

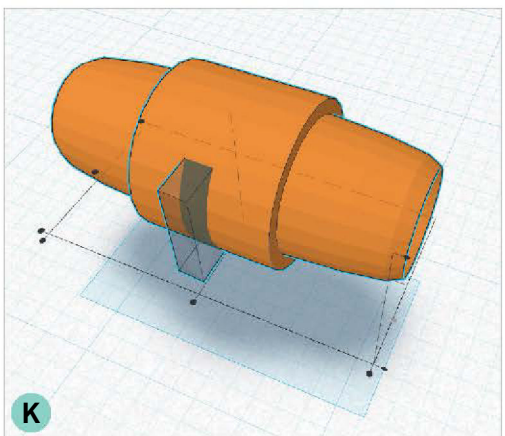
3. Select the torus and use the white middle grip to stretch it down over the cylinder. Use the conical grip to raise or lower it so it covers the cylinder properly. This will create a barrel shape (Figure G).

Group the shapes. Click the Ruler onto it (Figure H) to access the text fields and type the desired dimensions. If you want to change the proportions, stretch the barrel; the grouped shapes will stretch as one.











4. Drag a tube into the workspace and resize it so that it's half the height of the cylinder, but a slightly larger diameter. Click the Cruise tool, grab the white grip, and cruise it to the top of the cylinder (Figure I). Then click the Align tool and align their centers (Figure J). Alternatively, just use Align directly. Group the two shapes.

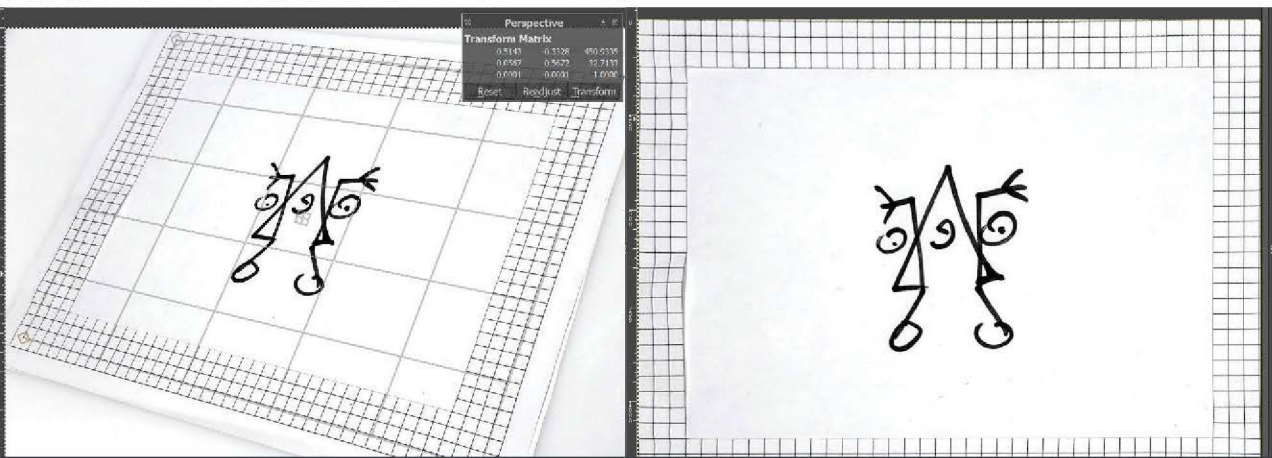
5. Drag a box into the workspace, size it 2mm wide, make it a hole, and center with the Align tool (Figure K). Make sure the box cuts deep enough into the handle to accommodate the bank's metal lever. Then group the shapes.

Figure L shows the 3D-printed handle!

CORRECTIVE PERSPECTIVE

Capture perfectly aligned vector images from your skewed photos, for free

Written and photographed by Tim Deagan



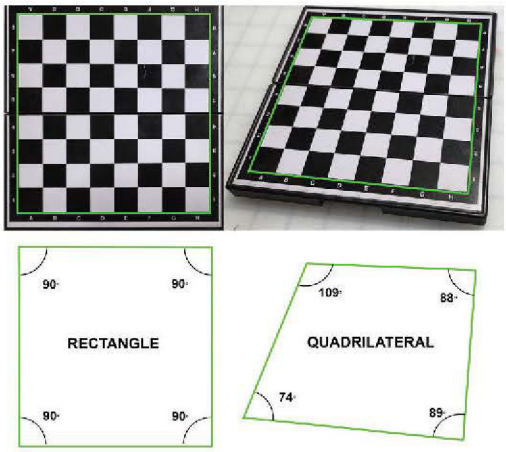


TIM DEAGAN makes, breaks, and collects things in Austin, Texas. He loves the experience of using software to breathe life into hardware with any microcontroller he can get his hands on.

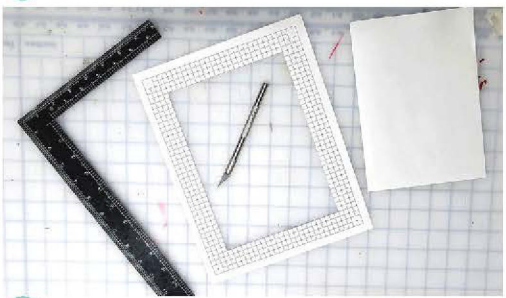
Using digital fabrication tools to re-create designs found in the physical world is a lot of fun. But capturing dimensionally accurate designs, especially with fixed-lens camera phones, can result in skewed images that can be tricky to scale. Unless you've used a perfectly aligned camera stand, most photographs have perspective problems due to the camera and image not being in exactly the same plane.

Shaper, the company that makes the Shaper Origin handheld CNC router, sells a fascinating product called Trace (shapertools.com/en-us/trace). It consists of a rigid plastic frame and a one-time fee for access to their online application. Shaper's goal is to create the simplest possible workflow for ***deskewing***, scaling, and converting photos to vector SVGs directly from smartphones. The Trace frame, covered in fiducial markers, sits on top of the design to be photographed to provide a reference scale and perspective. For folks frequently performing these operations, Trace offers considerable time savings and simplicity.

But not everyone needs to do these operations often enough to make the expenditure pay off. Luckily, it's possible to correct perspective, scale, and trace photos using a completely free (and open source) toolchain. To accomplish this we'll use two tools: the raster image editor GIMP (gimp.org) and the vector image editor Inkscape (inkscape.org), along with a DIY fiducial frame.



A Skewed quadrilateral overlaid on image.



B Reference frame on paper.

MAKING MARKERS

Perspective correction tools generally function by adjusting a skewed quadrilateral with varying internal angles into a rectangle with consistent 90° internal angles (Figure A). This is a software method of mimicking the use of a camera stand to get a perfectly aligned overhead photograph.

To make this process easier, it's extremely helpful to have fiducial markers defining where the corners of a known-size rectangle are. It's rare to find these in the wild, but we can add them by creating a reference frame and placing it around the image we want to capture. Our frame provides four dots to mark the corners of our rectangle, and a ¼" grid around the edges.

This frame can be cut and engraved on a CNC or laser cutter, or even be printed on paper with a home printer! The center section should be cut out so that you can overlay the frame on the image being captured. Cut it out with your digital fab tool, or with a craft knife if printed on paper (Figure B).

FIDUCIAL MARKERS

The term *fiducial* comes from the Latin *fiducia*, to trust. Since our ability to trust the orientation and scale of items in images frequently relies on a reference of some kind, these are often called ***fiducial markers***. These markers vary from simple comparisons of scale, like including a ruler or coin in a photo, to the highly precise Réseau crosses seen in NASA images from the moon landings. QR codes often have a square with an outline in three corners to provide orientation. Multicolor printing systems typically rely on registration marks to align different color runs. Pick-and-place robots rely on circuit pattern recognition marks to accurately locate and plop down tiny SMT components onto a circuit board.

Whether you use a ***cardinal*** method, e.g. a grid of known size, or an ***ordinal*** system like a banana for scale, fiducial markers provide a great way to get a better understanding of what you're looking at.



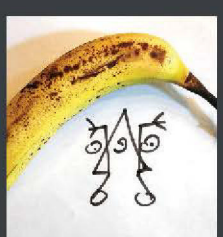
Réseau crosses on NASA moon landing photo.



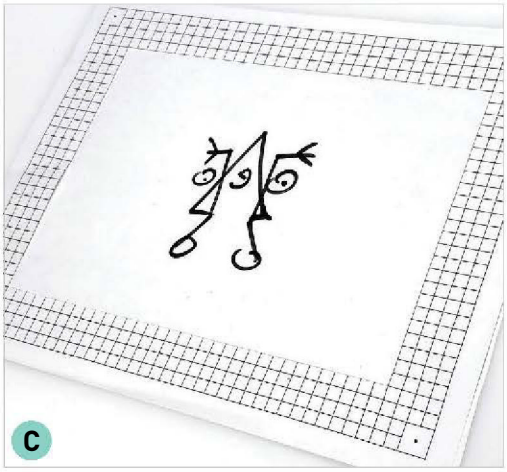
QR code.

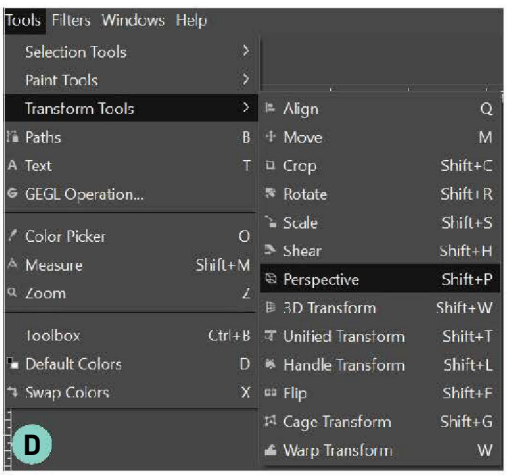


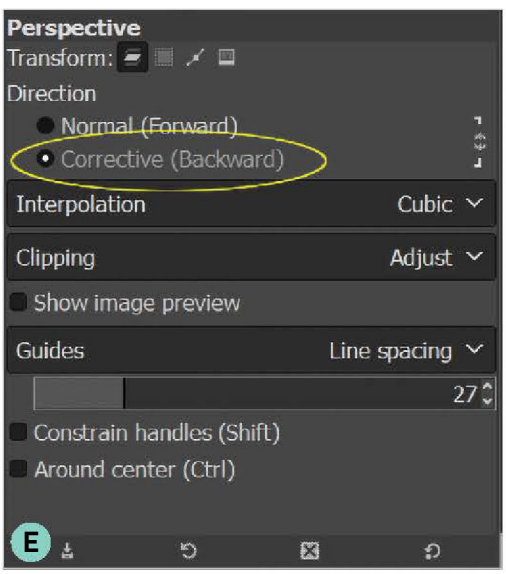
CMYK printing registration marks.



Banana for scale.







CAPTURING AN IMAGE

Once you have your reference frame, set it down on the image you want to capture (Figure C). This process works best with flat, 2D images. Capturing 3D images is not impossible, but adds significant challenges — e.g. shadows, hidden sides, and overhangs — that are beyond the scope of this article. A more common practice is to trace the outline of a 3D object. If this is your goal, do your best to keep the trace as tight as possible to the object edges. This helps avoid changing the size of the object once it's digitized.

Take a picture with your smartphone or other camera. Do your best to avoid shadows on the object being captured, as they will complicate the tracing algorithm in later steps. But remember that trying to take a picture without casting a shadow on the object is often what moves your camera out of true with the target and causes a skewed image! Using our fiducial reference frame and corrective perspective software tools will allow us to break out of this conundrum.

Transfer the image from your camera to your computer by your favorite method. GIMP and Inkscape are available on MacOS, Windows, and Linux platforms. Once you have the image on your computer, open it in GIMP.

DESKEW AND SCALE

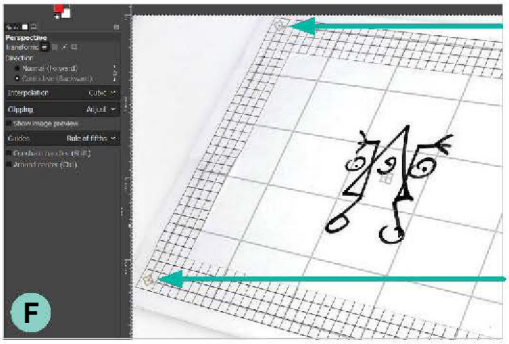
GIMP has many more tools than may be immediately obvious. Since your layout may be customized, the easiest way to find the tool we want is to click on the Tools menu (Figure D).

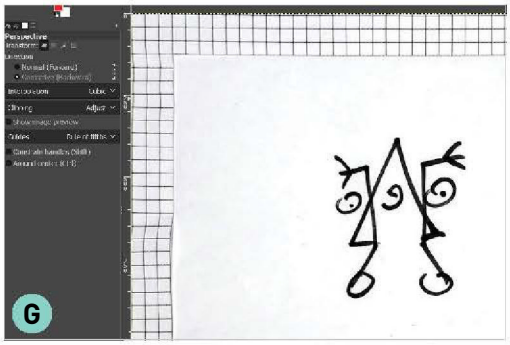
The Perspective tool offers a number of configuration options. For the Direction, choose Corrective (Backward) (Figure E). It's worth experimenting with the other configuration options to meet your personal preferences, but this one is the one that really matters.

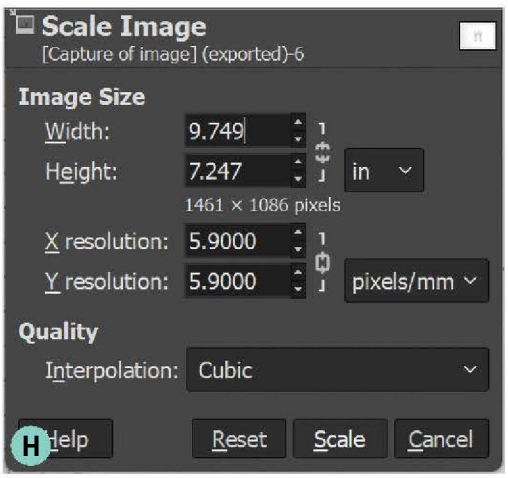
Mapping is achieved by placing the corners of the Perspective tool's grid to the corner points on our paper grid (Figure F). Pro tip: Zoom in on each corner. I found that using points as the corners instead of just extending the frame's grid made this easier.

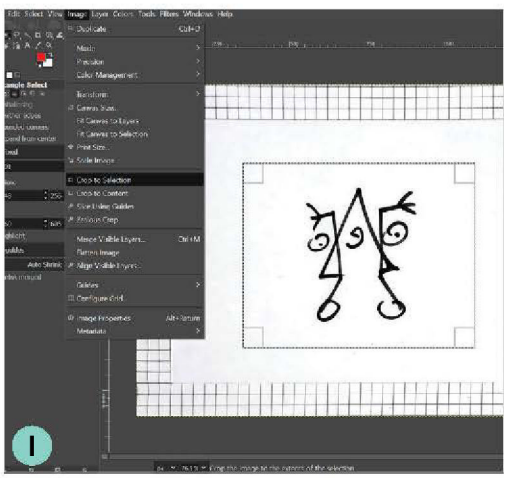
Once mapped, click the Transform button (Figure G).

The default Clipping setting will crop the image to the mapped grid. This is great since we know









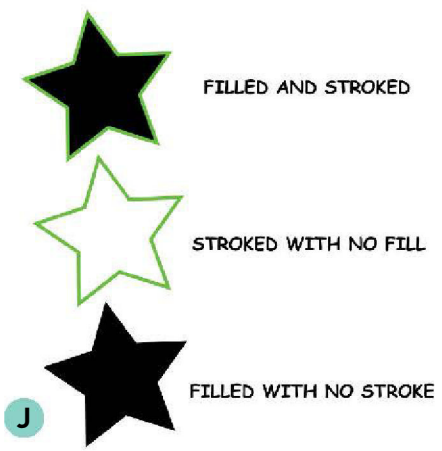
the dimensions of the paper grid at the points where we mapped it. In this case, it's 9.75"×7.25". We can use those dimensions to scale the image to its original dimensions (Figure H).

Next, we'll move over to Inkscape software for tracing. To make that step easier I prefer to crop out everything but the target image for my export out of GIMP (Figure I). Export the image to JPG or PNG format and save it somewhere you can find it for our next step.

TRACING THE IMAGE

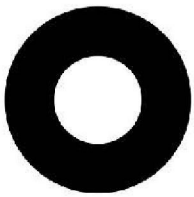
Open the saved image in Inkscape. Even though it's a vector editor, Inkscape will handle raster images fairly well. But we want to convert the raster image we captured into vectors and will Inkscape's ***tracing*** capability to do so.

Tracing is possible by using a variety of algorithms to determine the outer boundaries of shapes. A boundary defined by a set of ***nodes*** is called a ***path***. It's important to note that even a straight line will trace as a bounded shape area

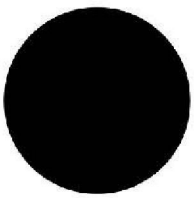


(like a very thin sausage) unless the ***centerline*** tracing algorithm is used. Vector tools like Inkscape present these bounded shapes either ***filled*** or unfilled, and ***stroked*** (outlined) or unstroked (Figure J). The fill and stroke can be the same or different colors.

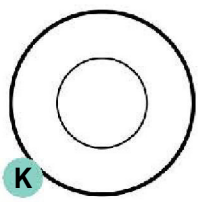
Fill and stroke are important to understand for



TRACED WITH OUTER RING FILLED WITH BLACK AND INNER RING FILLED WITH WHITE, PATHS ARE 'COMBINED'

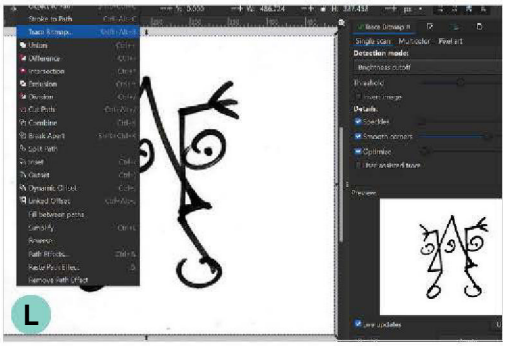


AFTER 'BREAKING APART' PATHS BOTH WERE FILLED WITH BLACK, HIDING THE CENTER PATH

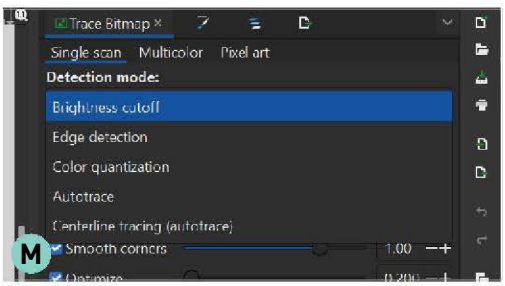


REMOVE FILL FROM EVERYTHING (AND KEEP STROKE) TO SEE ALL THE PATHS

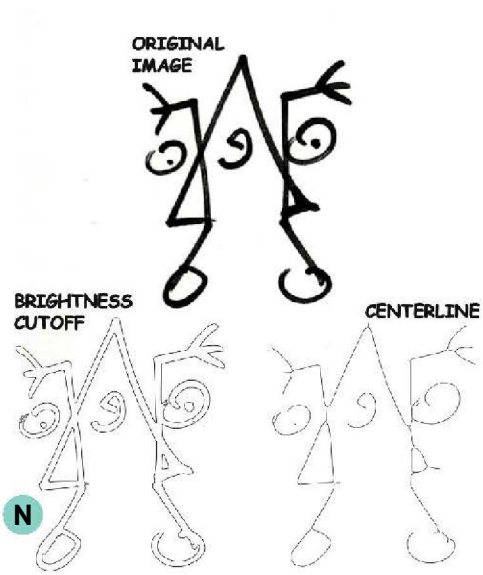
K



L



M



N

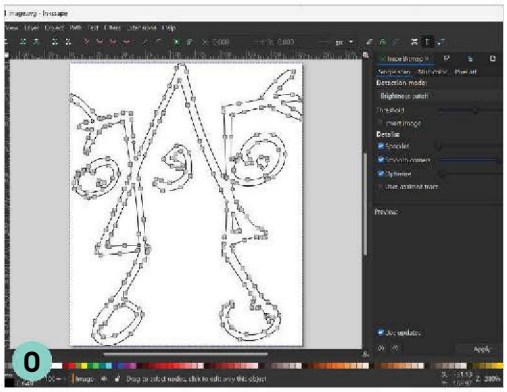
tracing because the tool will attempt to re-create the image as best it can. If it traces a shape that's black, it will fill the shape. A "hole" in the shape which originally showed the white background becomes a white shape on top of the black shape. Operations that break these shapes into separate paths often get confused and fill them with same color so that they get lost (Figure K). If you trace a toroid (donut) shape, it will create two shapes — the outer circle and the inner circle — as independent of each other. You have to perform a Boolean ***difference*** operation to remove the inner circle from the outer circle if you want a more complex path that would only fill the donut ring and leave the center empty.

Select your raster image and use Path→Trace Bitmap to choose a tracing method (Figures L and M). Then hit Apply at the bottom of the Trace configuration window. The resulting trace will appear directly on top of the traced image, often so good that it's invisible. Click on a filled area and drag it to the side to separate the vector from the raster. You can delete the raster image if desired. Select the traced vector and remove the fill to see the paths.

Looking at the stroked paths without fill can be important if you want to use your trace with digital fabrication tools such as routers, lasers, or

dragknife tools like vinyl and craft cutters. These paths are usually what the toolhead is going to follow if you're using it in a mode other than recreating a raster image row by row.

Centerline tracing is a more challenging algorithm for the app to execute well (Figure N). Rather than simply finding where there is and is not a shape and describing the boundary, Centerline tracing has to determine the midpoint between the edges. This can be very useful for operations such as V-carving on a router, but may require some manual editing to be satisfactory as a path.


O

EDITING AND SAVING

Your vector trace can be edited using the Inkscape native path tools (Figure O). A path consists of nodes that define corners, ends, and curves. Nodes can be manipulated, added, or deleted as appropriate.

Once the desired edits, if any, are complete, simply save the file in Inkscape's native SVG format for use in LightBurn, SheetCam, Fusion 360, VCarve, or your preferred CAM tool.


P

USING YOUR SVG

To provide some fabrication examples, I used the SVG from this article to make a vinyl sticker (I puffed out the paths a little) (Figure P), a to-scale cutout on my CO_2 laser, and one on my CNC plasma cutter (Figure Q). Each tool needed a few tweaks to handle different kerfs and idiosyncrasies, but the ability to replicate the image without skew and to scale is very exciting.

Can't you just put your artwork on a scanner to avoid skew and scale problems? Sure — if you have a scanner — but in many situations, using your phone camera is more effective, which frequently introduces the skew and scale issues we've worked through. Capturing graffiti, natural forms, building outlines, or other shapes "in the wild" are use cases where this process shines. I hope it adds new abilities in your shop!


Q



Video Game Module for Flipper Zero

$49 shop.flipperzero.one/products/video-game-module-for-flipper-zero

I've been a huge fan of the Flipper Zero multi-tool device since backing it on Kickstarter in 2022, and it just keeps getting better. The original firmware allowed you to do a bunch of cool and helpful stuff (see *Make:* Volume 83, page 124), but the addition of the mobile app, app store, and Wi-Fi expansion board have really transformed its utility. I take it everywhere I go (except in regions that have passed bizarre, ignorant bans on its use!).

So I was intrigued when the Video Game Module for Flipper Zero arrived in the mail. The form factor is delightful: unlike other, bare-board modules, the VGM's plastic case conforms to the Zero for a single cohesive combination device that looks and feels great. The headline feature of the VGM is its ability to push 640×480 pixels at 60Hz over HDMI — using just an RP2040! An IMU adds new control possibilities, and exposed GPIO pins from the RP2040 mean you can add things like joysticks or sensors into your games or projects.

I talked to Flipper Devices architecture chief Sergei Gavrilov about the project, and it turned into a sort of review of the RP2040, so I present a *Make:* first — a Toolbox review-within-a-review:

The most interesting challenge was generating the DVI signal. Here, we used the PicoDVI library a lot, which, frankly speaking, served as the project's catalyst. It generates a DVI-compatible signal using PIO, DMA, and a slightly overclocked processor.

Overall, the RP2040 left very positive impressions on us. I don't recall similar PIO modules in other microcontrollers. The second core allows a perfect separation of real-time and non-real-time code levels. Of course, the RP2040 lacks a capability for floating-point arithmetic operations, and even dividing simple numbers requires a special approach, but all of this is offset by a sufficiently high clock speed and the simplicity of further overclocking.

The VGM is just $49; a Flipper is recommended, but not technically required, thanks to the VGM's built-in USB-C port that allows standalone usage and flashing of firmware. —*David J. Groom*

Flipper Devices



Keychron Q1 HE

$219 keychron.com/collections/keychron-q-he-series-keyboard

The Keychron Q1 HE is a unique 75% (82-key) luxury mechanical keyboard that features hot-swappable Hall-effect Gateron Nebula double-rail magnetic switches. Unlike traditional mechanical switches that have a single, fixed actuation point, these magnetic switches offer 0.1mm sensitivity along the entire 4.0mm actuation range, meaning you can customize your actuation point as you wish (per key!). And here's where things get really crazy: you can define up to four actuation points per key, allowing for example a slight press to be bound to a walking action in a game, then transition to running at the next threshold. The HE also features a new 2.4GHz connection with 1000Hz polling, in addition to three Bluetooth 5.1 slots and USB-C wired. The 6063 aluminum chassis and double-gasket construction provides a luxury feel and sound, and a 4000mAh battery provides hundreds of hours of wireless operation between charges — depending on your usage of the south-facing RGB LEDs and their 22 effects! The Q1 HE is available from Keychron's site for $199 barebone without keycaps and switches, or $219 fully assembled. —*David J. Groom*



Arduino Alvik

$140 store-usa.arduino.cc/products/alvik

I was lucky enough to get a sneak peek of Arduino's new Alvik robot back in October on a visit to Arduino's offices in Turin, Italy, after Maker Faire Rome, and now it's finally available for all to enjoy! And I do mean all: thanks to block-based programming (coming soon) and MicroPython support, Arduino's new bot should appeal to a wide range of makers, from elementary school students to seasoned pros. Unlike other Arduino products that might only blink out of the box, Alvik comes pre-programmed with great demos, including line following and the ability to choreograph a sequence of movements using the built-in capacitive buttons. Once you've played around with the examples, you can dive into their code with the Arduino Lab for MicroPython editor, seeing how they work and bending them to your will thanks to the MicroPython firmware already installed on the built-in Nano ESP32 board. With onboard locomotion, power, and sensors including distance, color, and 6-axis gyro, plus Grove, Qwiic, and Lego compatibility, Alvik is more than just a cute little bot — it's an entire platform for enabling your robotic dreams! —*David J. Groom*



A lamp project I cut on the WeCreat Vision.

WeCreat Vision

$1,150 wecreat.com/pages/wecreat-vision

Recently we've seen an explosion of affordable, open-gantry diode laser cutters based on solid-state UV lasers from the BluRay market. But these came at a high cost in safety: a reflection from an open-gantry UV laser can blind you before you can blink, even hundreds of feet away.

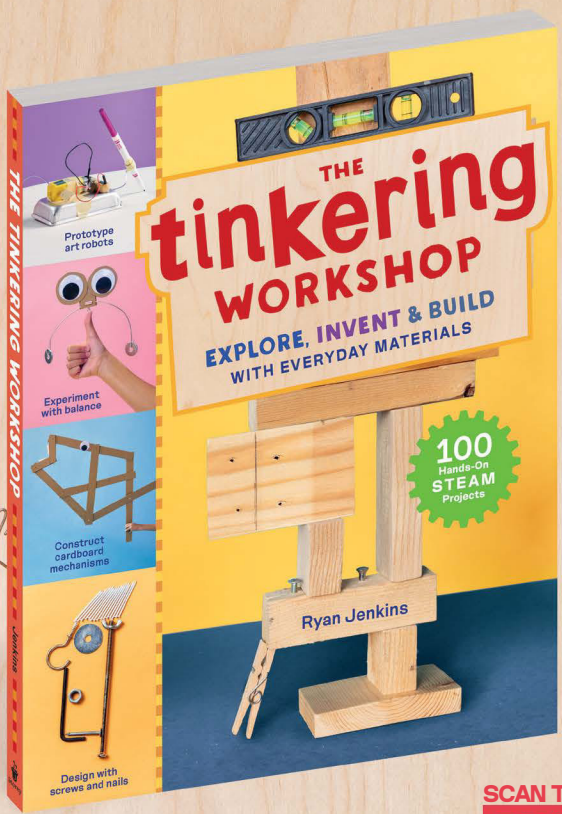
Rising to this challenge, the WeCreat Vision has found a perfect balance between convenience, safety, and functionality with one simple trick: it's a fully enclosed laser that automatically adjusts its height! The lid, made of UV-blocking polycarbonate, raises 140mm and has a built-in autofocus HD camera that makes it easy to align your cuts with your material. When fully extended, you can plug the rotary attachment into a port without unplugging the Y axis like on many other lasers. To engrave larger sheet goods, an optional (untested) extension allows 145" of material to be automatically fed through.

Another problem with affordable lasers is the software — typically awful and barely usable, or overly complicated. WeCreat has fixed this too with a great piece of software called WeCreat MakeIt! (yes, the ! is in the name) that's nicely featured and easy to use, allowing you to connect to the Vision over USB or Wi-Fi. The basic drawing tools are good enough, and I love that when picking power settings you see example images of how dark your engraving will be, rather than guessing at a number. My engraves and cuts came out great, although cuts were slow, typical for 20W diodes (I'd love to try the optional 40W head). I ran the optional fume extractor and while it helped, I do suggest venting outside. If you're in the market for a diode laser, especially one with a rotary for engraving mugs and such, the WeCreat Vision is a great option and at this time my top pick on the market. —*Matt Stultz*

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Anycubic Kobra 3 With ACE Pro $449 anycubic.com/kobra-3-combo

We are firmly in a new era of desktop 3D printing, punctuated by smarter, faster, and easier-to-operate printers. The Anycubic Kobra 3 just a few short years ago would have turned the entire industry on its head. Taking some of the best features from Voron, Bambu, and Prusa, the Kobra 3 feels less revolutionary and more like it shows exactly where the bar should lie today.

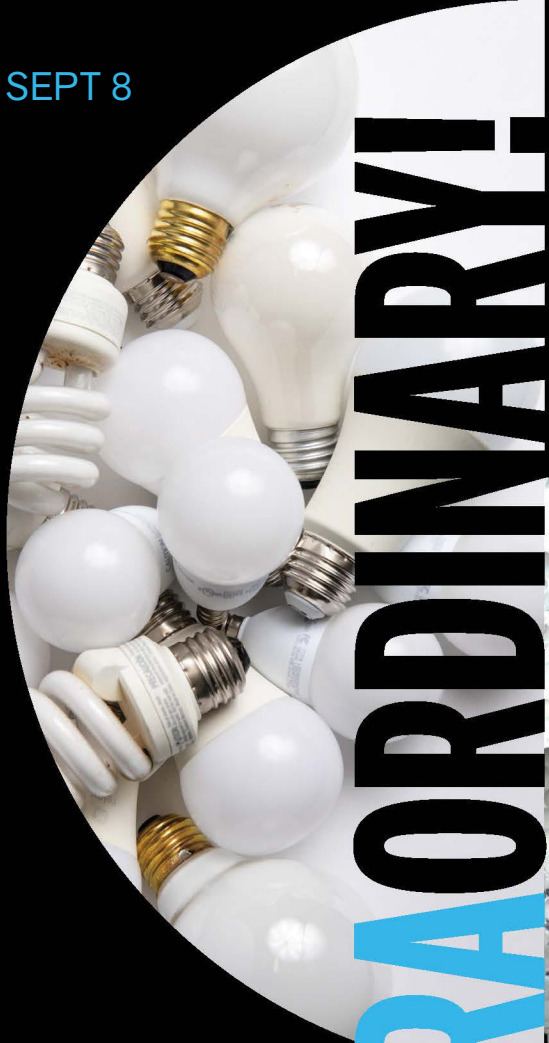
The machine I tested came with the ACE Pro multi-material accessory, an external box that feeds up to four spools of filament into the Kobra 3. If four aren't enough, two units can be linked, for up to eight spools. And don't worry about it absorbing moisture: the device doubles as a filament dryer.

Unpacking and setting up this bed slinger is fast and easy. You follow the on-screen prompts as the machine uses its collection of sensors to set up the printer for your first print. There's no bed leveling or Z-offsetting chore: the Kobra 3 uses direct nozzle-to-bed leveling. Other sensors test the resonance of the printer, so it can be tuned to run fast and accurately (600mm/s without ringing defects), or detect filament tangles and nozzle clogs, pausing the print for user intervention (something I successfully experienced). There are other fun aspects — quick-change nozzles, PEI bed sheets, RFID filament detection — but in the end these just pile on to a great machine.

There are a couple of things I'd change. The cable connection, on the front of the Kobra and the back of the ACE; is awkward and in the way. And people joke about the "poop chute" on Bambu machines, but the Kobra 3 could be nicknamed the Capuchin for its "poop flinging" mechanism to deal with the filament change waste — when your floor is covered in little filament twists, the joke ends quickly. I also don't see a firmware source for the Kobra 3; it's almost undoubtedly based on Klipper.

Given the price and ease of setup, I'd easily recommend the Kobra 3 as a first printer if you want something beyond the basics — in fact I'd say it's a steal. —*Matt Stultz*

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Animated Ground Breaker Kit

$205 spiderhillpropworks.com/animated-prop-kits_c_22.html

While I've assembled plenty of store-bought props and animatronics, I had never actually built one myself. For my first DIY Halloween prop, I chose the Animated Ground Breaker kit from Spider Hill Prop Works. It comes in two versions: basic for $185, and complete for $205 with all the pre-cut lengths of PVC pipe you'll need. I tested the complete kit, and the extra $20 is worth it. With either kit, you'll need to provide a 1"×6"×24" wood base. The instructions were easy to follow, with clear diagrams and photos; in a couple of hours I was able to assemble the kit. It utilizes a wiper motor, drive arms, and a wiper motor power supply with a speed controller to automate the motion. Now I just need to add a monster mask, gloves, and ratty clothes, and I'll have a zombie struggling to pull itself out of its grave. *—Paul Benson*



Siser Romeo **$699** siserna.com/romeo

I'm a relative newcomer to vinyl cutters; I've played around with a Cricut, but found it tedious and hard to get working reliably, so I never got hooked. Until I got my hands on the Siser Romeo, a luxury machine from Italy that I can't put away. Setup was easy, even for a novice, and the included software, both on the device and for your PC (or Mac), makes the cutting process easy and fun, even if you have no idea about things like blade angle and force. Plus once it's on your Wi-Fi, you can start jobs from the other side of your workshop while stowing the machine in a convenient spot. Built-in settings for adhesive and heat-transfer vinyl tend to cut perfectly the first time, and can be customized as needed. I'm barely scraping the surface with my usage, but I'm running out of items to plaster "ishotjr" stickers on, so I'm looking forward to making sublimation stickers, T-shirts, and more. The Romeo is truly the Ferrari of vinyl cutters, and it won't end up forgotten in my garage. *—David J. Groom*

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DRINKS ARE ON ME!

Anouk Wipprecht has been dazzling the world with her mind-blowing FashionTech designs for the past two decades, with each piece presenting new perspectives on the interplay between technology and fashion. Her new design, DRINKBOT 2.0, represents the latest evolution in a line of uniquely interactive dresses. Building upon the original robotic cocktail dress, DareDroid, which required the user to engage in a game of Truth or Dare in order to earn a drink, and the peristaltic-pump-powered DrinkBotDress, the 2024 design pushes the envelope yet again with new levels of functionality and creativity.

At the heart — or perhaps brain — of the project, is BeagleBoard's new BeagleY-AI board, which empowers the dress with voice interaction, thanks to its advanced DSP deep learning accelerator cores, plus a USB soundcard and lavalier mic. Six Adafruit peristaltic liquid pumps, driven by a DC motor HAT, allow alcohols, bases, and syrups to be squished through silicone tubing and combined to deliver the selected cocktail, ingredients, or color. The resulting concoction is then emitted into a shot glass in a 3D-printed cup-holder. A USB power bank and liquid-holding belt round out the system. The 2.0 design is also unique in that it offers both male and female versions of the concept.

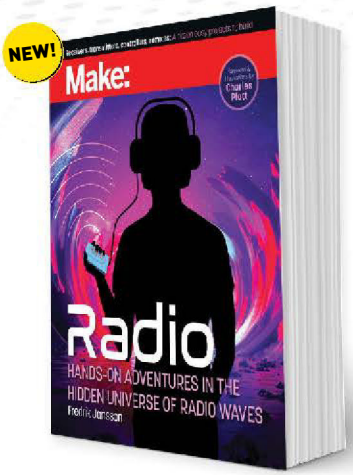
Once you're done marveling at this ground-breaking fusion of open-source hardware and innovative design, you can learn more about it and the process involved in its creation, plus see this and more of Anouk's creations in action, at makezine.com/go/drinkbot20. *—David J. Groom*

Yanni De Melo

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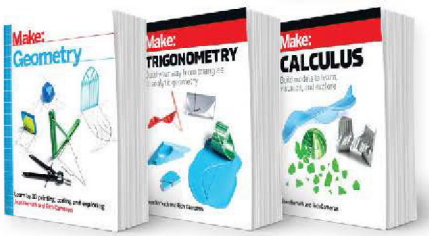


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By Fredrik Jansson
Foreword and illustrations by Charles Platt

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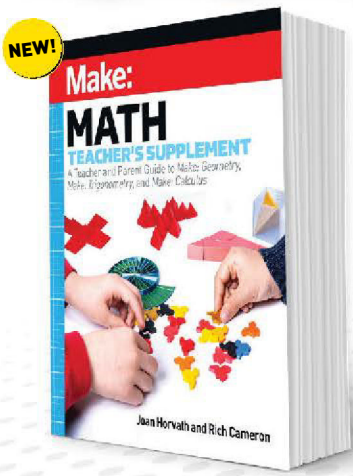


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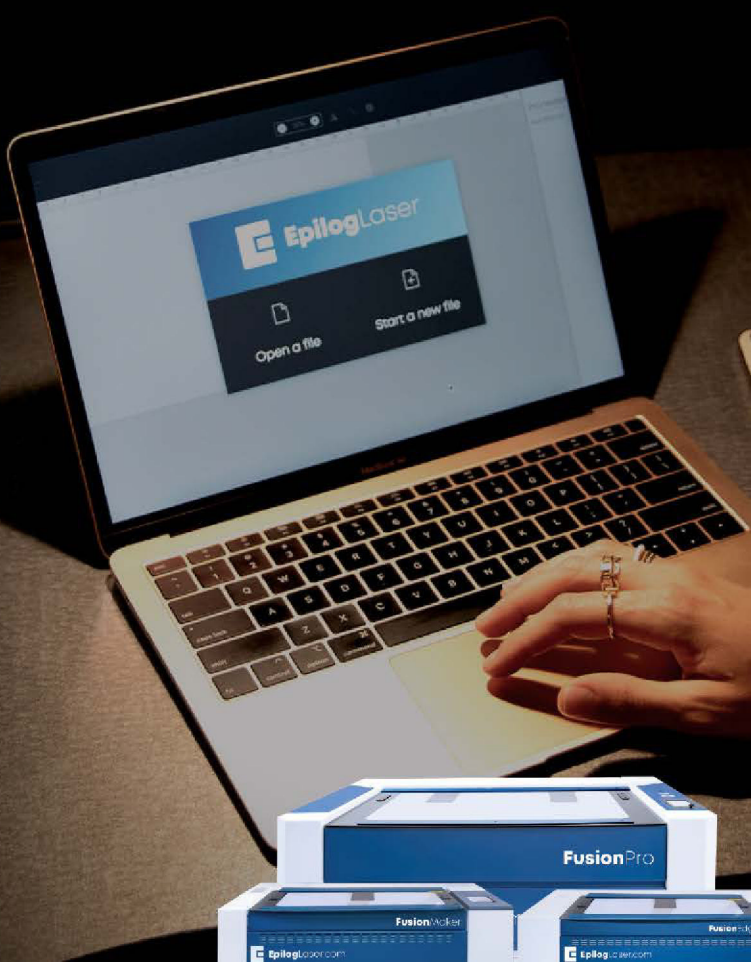
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