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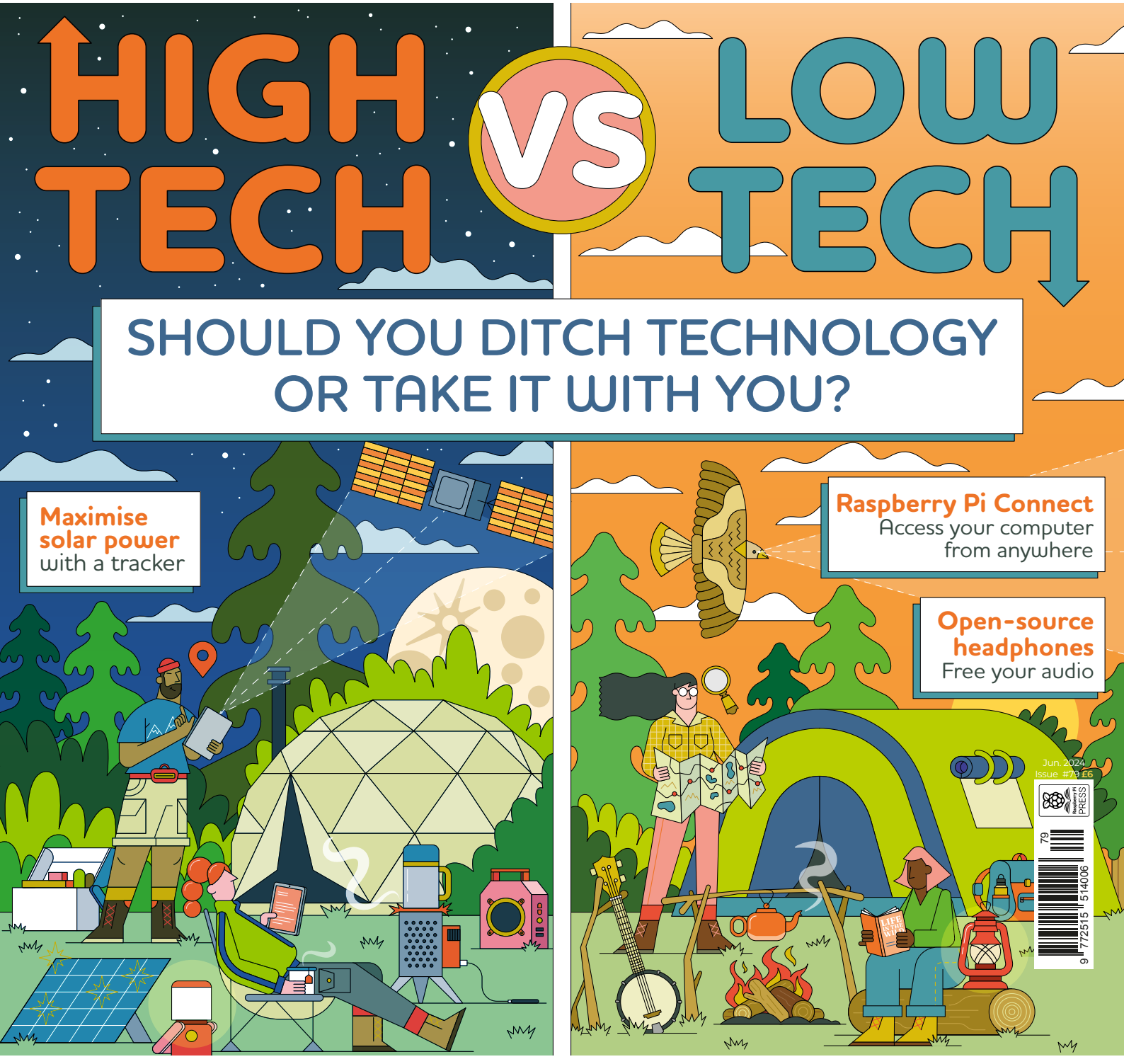
HackSpace

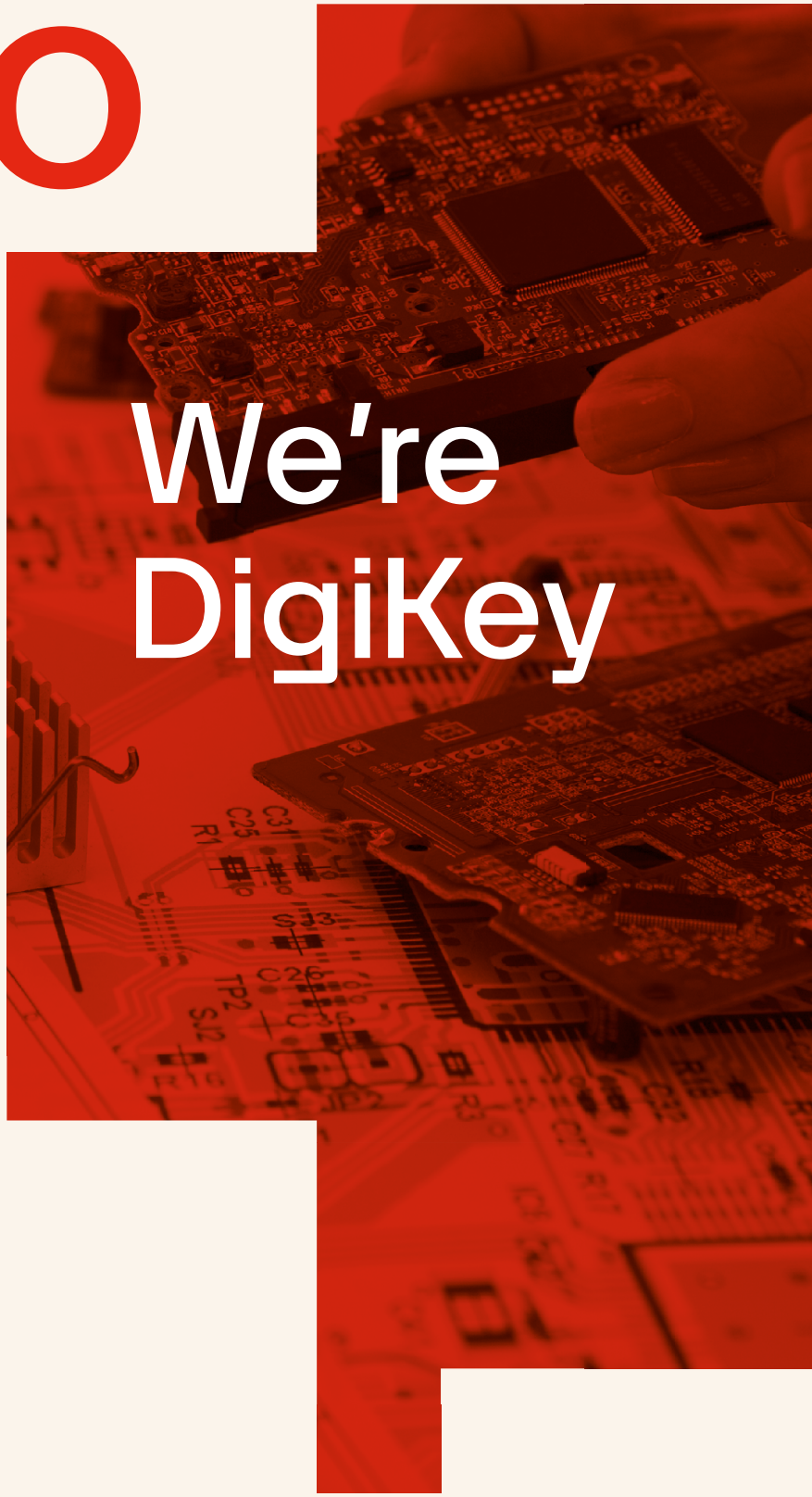
TECHNOLOGY IN YOUR HANDS

hsmag.cc | June 2024 | Issue #79



WOODWORK AI 3D PRINTING GUITARS

Hello



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Welcome to HackSpace magazine

Spending time in nature makes you happier and healthier. However, there's more than one way to enjoy the great outdoors, and this month we're investigating whether or not we should take our gadgets and gizmos (whether or not they're homemade) with us. We don't mean just taking a laptop and ignoring nature, but bringing the little bits and pieces that can smooth over some of the rough edges of the outside world.

I'll give you a little spoiler, though. We're not going to pick a winner. This isn't because we're copping out, but because there's no right or wrong here – at least not a universal right and wrong that's the same for everyone. We don't want to tell you what to do; we want to help you find the way that's right for you. That you spend time in nature is more important than how you do it.

BEN EVERARD
Editor ben.everard@raspberrypi.com

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ISSN: 2515-5148.

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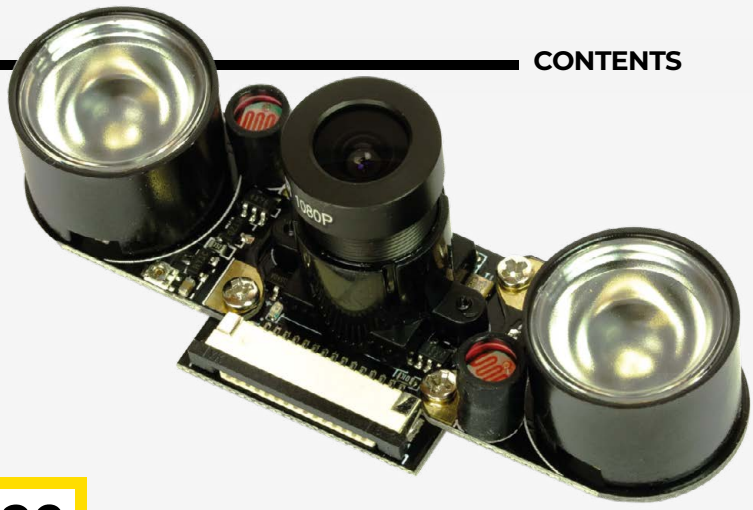
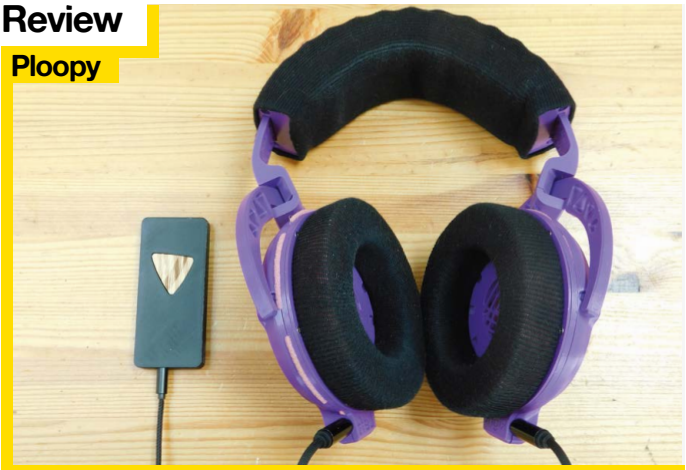


Interview

Jón Schone

Review

Ploopy



49 FORGE

85 FIELD TEST

REGULAR

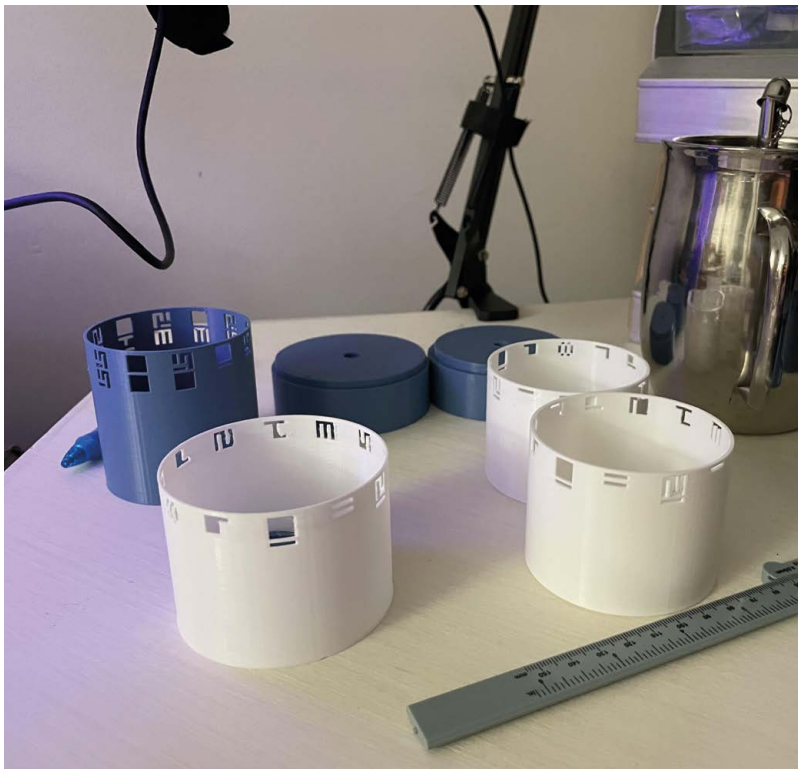
Column clock

By **ReallySrry** hsmag.cc/ColumnClock

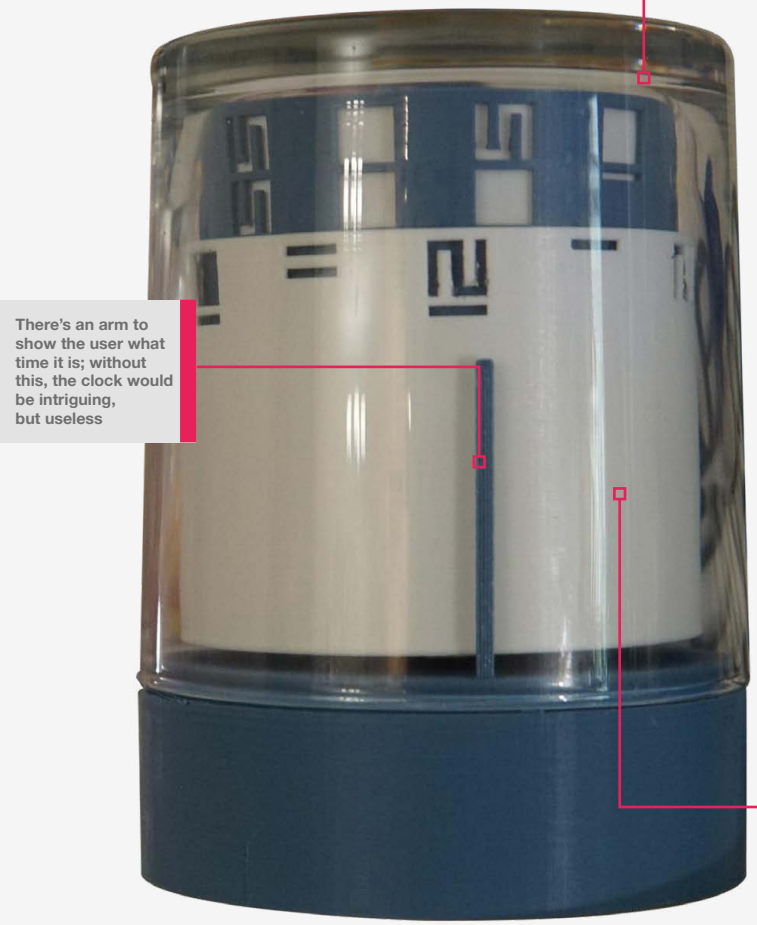
We're used to seeing creative ways to display the time in these pages, but most of the time, that trends towards complexity. The marble clock we featured in issue 78, for example, was a masterpiece in needless complexity.

This clock by ReallySrry takes the opposite approach. It has just two moving parts, just like an old-fashioned analogue clock. In fact, the maker has repurposed an off-the-shelf clock mechanism bought for under $10, so there's no need for fancy microcontrollers or anything that needs programming.

As it's built on a standard clock assembly, this device works in a pretty familiar way. The time is displayed on two concentric cylinders, with the outer white cylinder showing the hours and the inner blue cylinder showing the minutes. And that's it.



Right
It took a few iterations to get the numbers to print correctly, but that's the magic of 3D printing – if it doesn't work at first, tweak it and try again

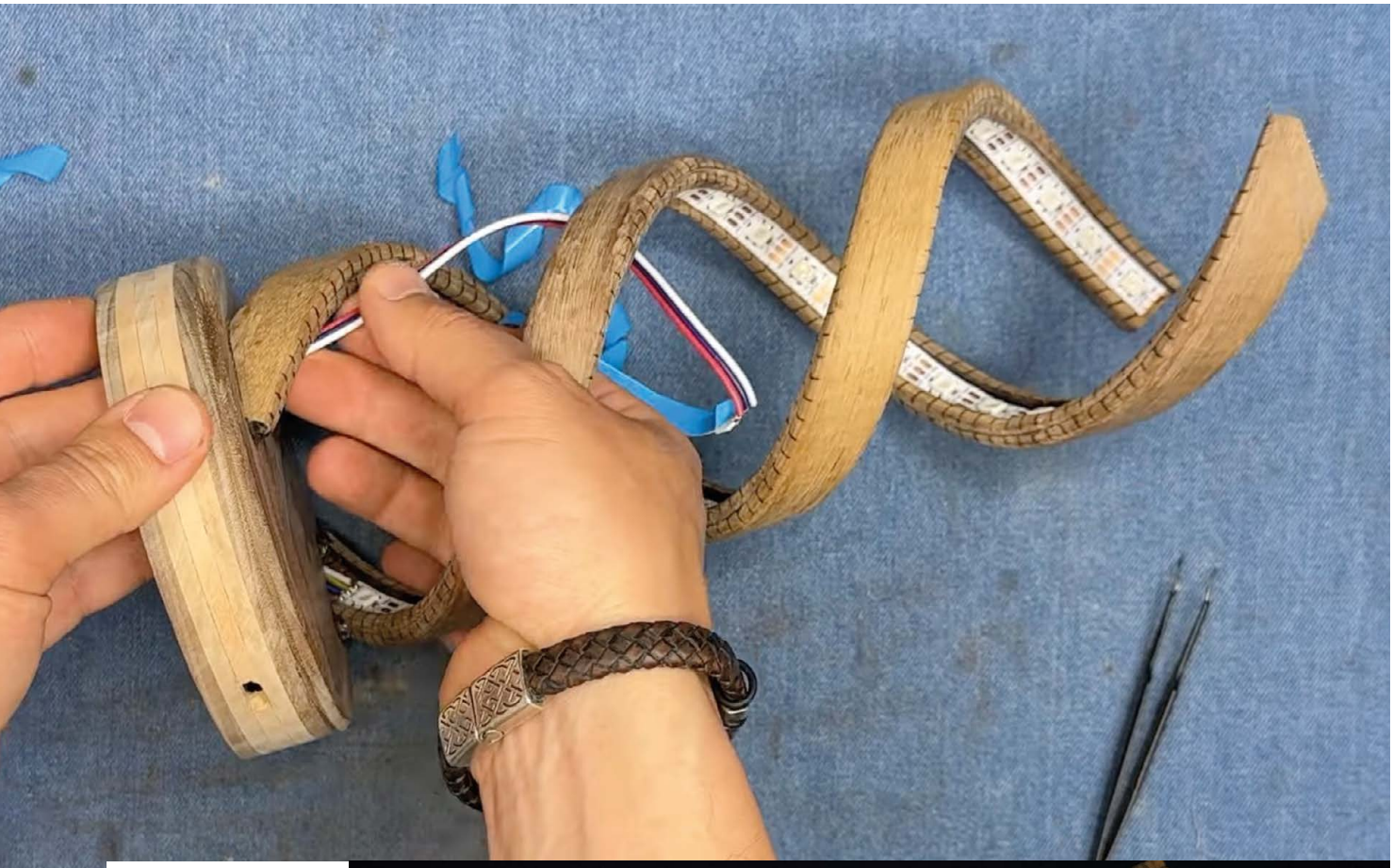

The clock's glass case is actually a drinking glass, turned upside down
There's an arm to show the user what time it is; without this, the clock would be intriguing, but useless
The white filament used is Polymaker PolyTerra White PLA, and the blue is Inland Cornflower Blue PLA, both printed at a layer height of 1.6mm

Gesture-controlled DNA lamp

By **Kostiantyn** hsmag.cc/DNALamp

Kostiantyn uses a laser cutter to score the inside of two wooden strips of walnut veneer, making them flexible enough to wrap around a cylinder. He brushes them with resin, so when the resin dries, it holds the shape of a spiral – do this twice, and you've got the beginnings of a DNA double helix made in wood. Add a plywood base, a strip of addressable LEDs and a PAJ7620U gesture sensor, plus an ESP8266 controller, and you've got a unique gesture-controlled desk lamp.

What we love about this project is that the woodworking element is just about possible to recreate without the laser cutter. All you need is a hand steady enough to cut hundreds of tiny lines to the same thickness, direction, and depth, and then do it again for the two strips that form the two strands of the DNA, and the thinner wooded strips that hold the NeoPixels in place, all without making a single mistake. That's the sort of work that more sensible makers such as Kostiantyn leave to the machines, leaving him free to do the more difficult, creative work, such as coming up with the idea in the first place. □



Right
Mini glass bottles represent the AT/CG base pairs, and give a nice diffuser effect

REGULAR

Fallout Cyberdeck

Right
Alas, nuclear bombs have become a lot more powerful since the 1950s. Nice try, though!

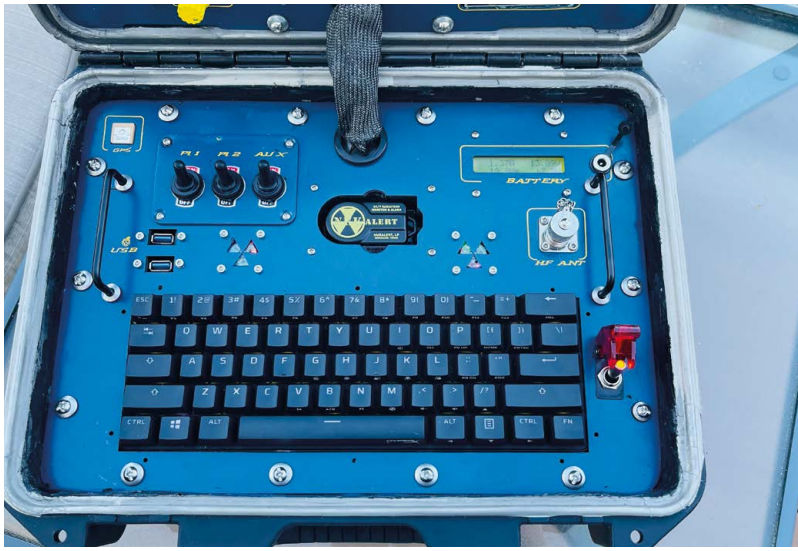
By **Eric B**

hsmag.cc/FalloutCyberdeck

If things keep going the way they are, humanity might be reduced to living underground, eking out a subsistence living and waiting for the radiation on the surface to reduce to such levels as we can repopulate the earth. Let's cross our fingers that this doesn't happen – but if it does, this cyberdeck, built by Eric B and inspired by the video game (and now television series) *Fallout*.

The active electronics are housed within two layers of conductive insulation, acting as a Faraday cage in the event of an electromagnetic pulse caused by a nuclear explosion. Battery life is an impressive 14 hours, and the device is loaded with tons of information for offline consumption – useful stuff, like medical information, Wikipedia, wikiHow and perhaps less usefully, TED Talks.

A range of software-defined radio apps gives the user the ability to communicate with satellites, track aircraft, pick up AM/FM radio and more, and computing power is provided by two Raspberry Pi 4s. It even has a radiation sensor, so you know when it's safe to come out of Vault 33. Good luck!

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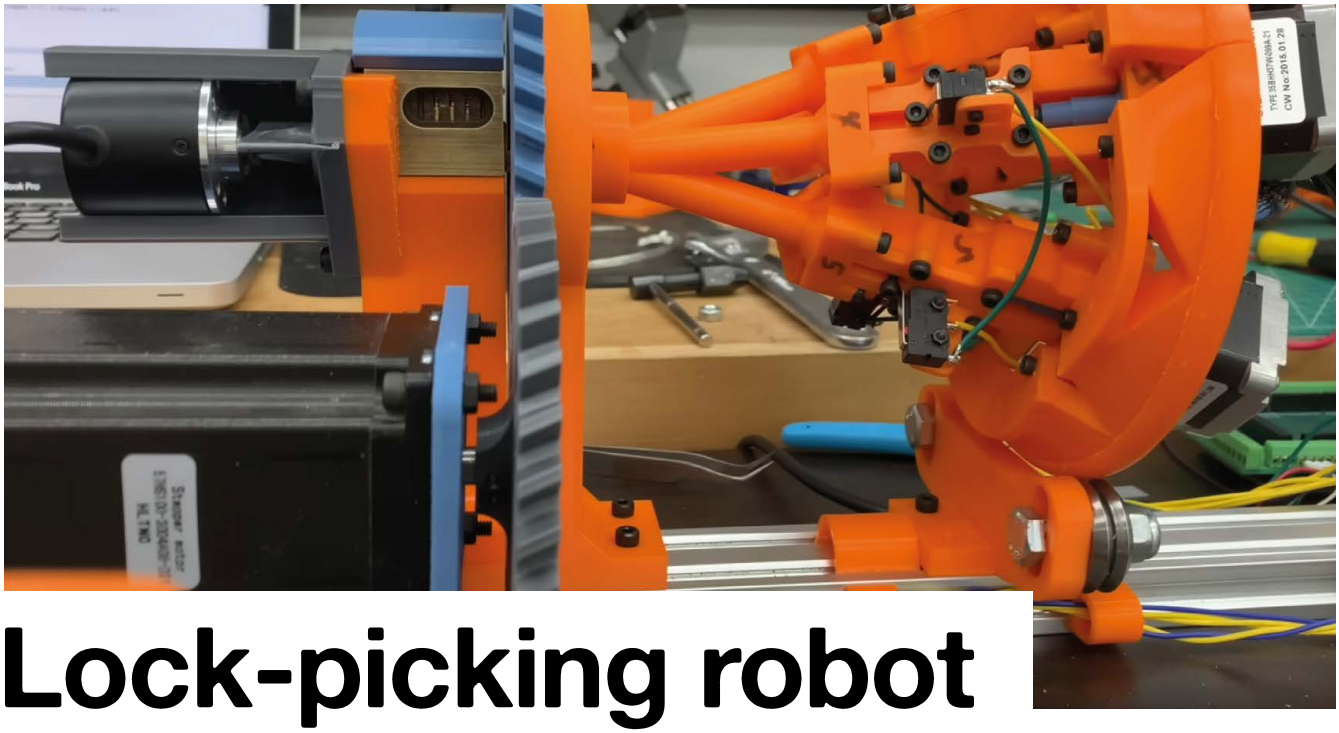


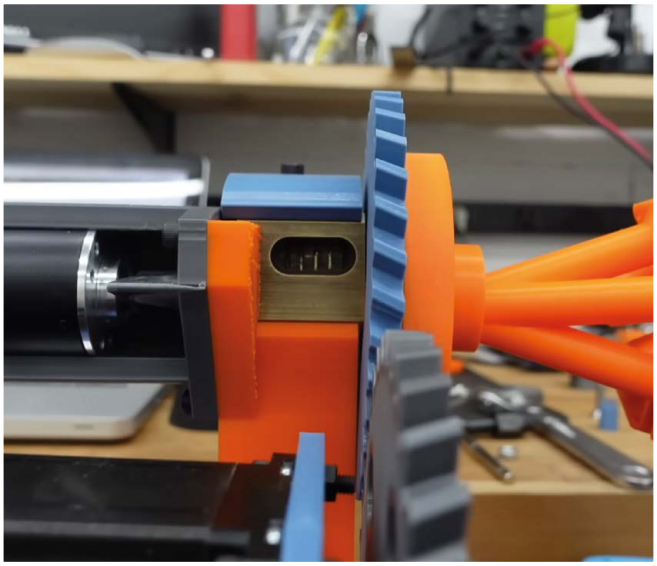
Lock-picking robot

By **Sparks and Code** hsmag.cc/LockpickRobot

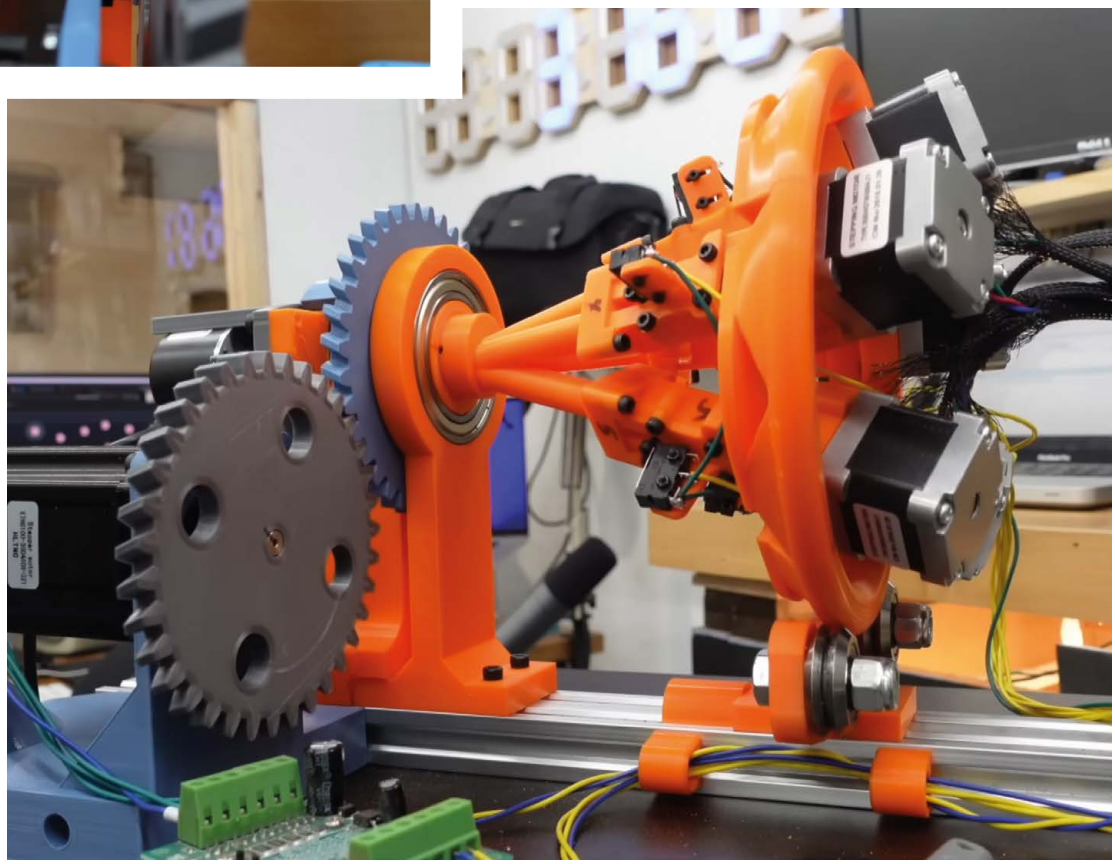
We've had a little look at lock-picking back in a past issue of HackSpace (Issue 48). The most important thing we remember from that tutorial is that you must never pick a lock that isn't yours. The next most important thing is that a Yale-style lock has several pins that must be pushed into place before you turn the lock. Normally you'd do this with a key – the irregular surface of a key is like that because each pin has a different amount of travel before it clicks into place and the barrel of the lock can turn. To open a lock without a key, you need to apply some gentle rotational force to the barrel (usually with a thin piece of springy metal called a tension wrench), and some way of pushing the pins of the lock upwards. The more pins, the harder the lock is to pick. Oh, and many, many locks are trivially easy to pick.

With the basics established, and a thriving community of security-aware hackers out there sharing tips (all in the name of hardening security, of course), it was only a matter of time until someone produced a lock-picking robot. And what a robot! This beauty uses a hollow 3D-printed key blade with five wires running through it, which pop out where you'd expect to find the teeth of a regular key. These push the lock's pins up while another motor rotates the key blade. There are only so many combinations that are possible, and the robot's software just cycles through all of these combinations in a physical brute-force attack.

We don't think many readers will want to replicate this machine – the plastic will most probably fail before the robot has cycled through all the possible pin combinations – but there is one aspect of it that we think all robot makers should think about, and that's the way it controls rotation. To ensure the machine doesn't try to rotate the machine while the lock is still closed, which would break the key blade, Sparks and Code has used an optical encoder to give feedback to the stepper motor, which will tell it to stop turning if the lock doesn't move.



Left
Always secure your bike with two different types of lock, so that thieves have to carry two types of machine

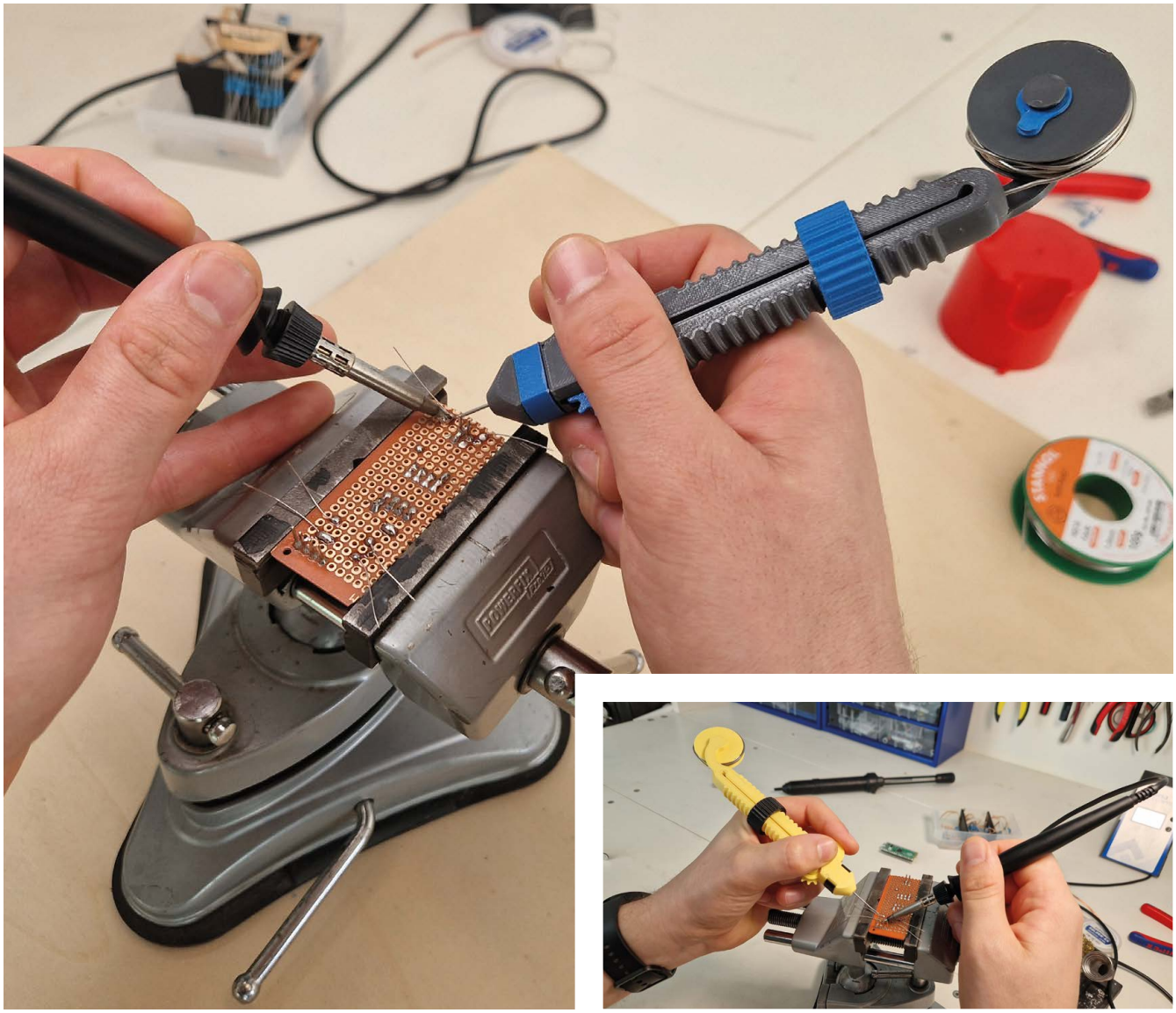


Solder Scroll

By **Victor de Boer** hsmag.cc/SolderScroll

Soldering anything, especially small components, needs at least three hands: one to hold the solder, one to hold the soldering iron, and one to hold the component. A small vice can help you here, or one of those devices with multiple flexible arms with crocodile clips to hold components in place. Despite that, soldering is still tricky. We tend to hold the spool of solder between the palm and ring and little fingers of our right hand, and thread solder toward the joint we're working on with our thumb and index and middle fingers. It's ungainly, and that's why the world needs the Solder Scroll. This brilliant device makes soldering more ergonomic by allowing you to dispense any diameter of solder out of an object you hold like a pen. It's fully 3D-printed, and the assembly requires no glue or metal fasteners: you just fit the parts together and adjust the big nut to accommodate whatever size solder you're using. Not only that, but it's a quick print job needing no supports, so if you find yourself contorting your digits while you're soldering, it's worth printing yourself – its designer, Victor, has shared the print files on the link above.

Right
The Solder Scroll can accommodate solder between 0.3 and 1.5mm in diameter – that's plenty for us



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Uncover the technology that's powering the future

PG 30

HOW I MADE: SOLAR TRACKER

One man's quest to build a device that will wring as much energy as possible from the sun

PG 36

INTERVIEW: JÓN SCHONE

Right, everybody put down your D&D models and stop being silly: it's time to do some proper printing


HIGH TECH
VS
LOW TECH

Modern homes are great! They can provide an ambient temperature all year round; there's endless entertainment on tap; food is kept fresh and can easily be prepared in myriad ways. Seats, sofas, and beds provide us comfortable places to be at any time of day. We humans have used our ingenuity to create these little slices of almost perfect comfort.

Why, then, do so many of us enjoy leaving this comfort behind and heading outside, sometimes just for an hour or two, but also for days at a time?

Our brains don't process carefully ordered bits as computers do. They're chaotic processors of vast amounts of sensory information, and they've evolved over millions of years to handle the outdoors. While we are now at home inside solid structures, we still have basically the same brain that we had when we lived on the savannah or in forests. Something about nature and the outdoors calms us and helps us process the stresses of modern life that we are ill-adapted to cope with.

This issue, we're going to look at the best way to get our dose of nature, to recharge our frazzled brains so we can get back to the workshop ready for more productive making. →

Navigation

Finding the way to find your way

Right
Can we find our destination without a direction?

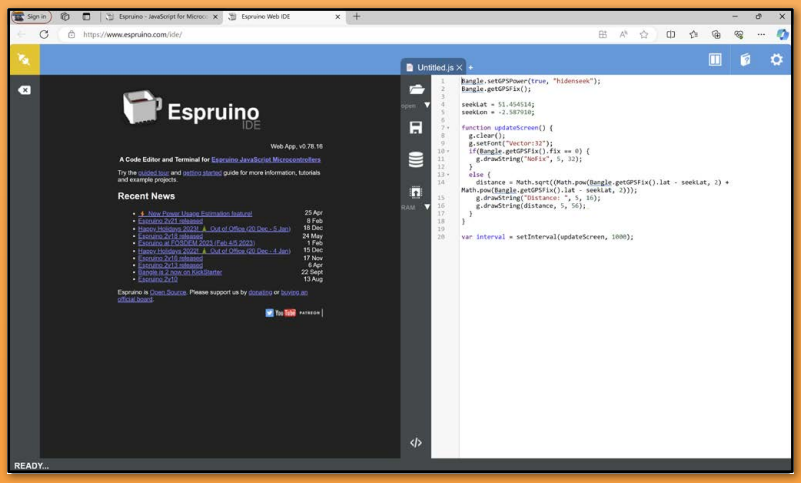
In the GPS era, navigation is, in many ways, a solved problem. While there might still be some challenges, in most cases, you can simply follow a line on a screen until you reach your destination.

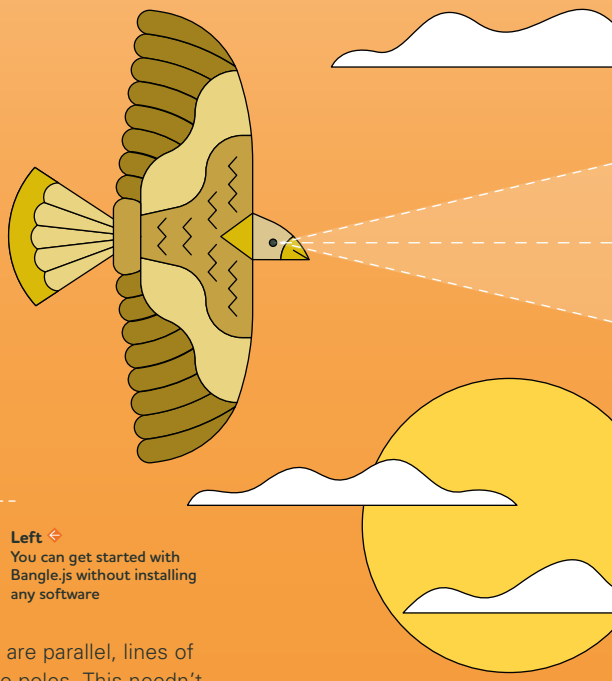
The question isn't really 'what's the best way to navigate', it's 'what's the most entertaining'. For some people, this might mean following the line on a screen. For others, it might mean using a map and compass, but there is a big area in between where we can have some fun.

One of the great things about high-tech stuff is how easy it is to modify software to create a new use for your gadget or gizmo. We're now going to have a play with one such device – the Bangle.js 2. This is a GPS-enabled smartwatch that's designed to be reprogrammed to your needs. We're going to take advantage of our hackable watch to build a simple script that tells us how far we are from our destination. It won't tell us which direction to go in, so it's still a bit of a search. While this isn't the most practical way of finding your way somewhere (the Bangle.js 2 does have a good selection of apps that can help you if you want something a bit more conventional), the brainwork and exploring are part of the experience.

Provided you've got a web browser that supports Web Bluetooth, you don't need to install anything. Just head to the Web IDE at **espruino.com/ide**.

For this quick example, we're not going to create an app; we're not even going to save our code onto the device, we're just going to create a script and run it. As the name suggests, the Bangle.js is programmed in JavaScript, but hopefully, anyone with some programming experience should be able to follow our example.





Left
You can get started with Bangle.js without installing any software

Before we can create our script, we need to connect to our watch. Click on the icon in the top left and select your watch from the available Bluetooth devices.

The code for our navigation script is:

```
Bangle.setGPSPower(true, "hidenseek");
Bangle.getGPSFix();

seekLat = 51.454514;
seekLon = -2.587910;

function updateScreen() {
  g.clear();
  g.setFont("Vector:32");
  if(Bangle.getGPSFix().fix == 0) {
    g.drawString("NoFix", 5, 32);
  }
  else {
    distance = Math.sqrt((Math.pow(Bangle.
getGPSFix().lat - seekLat, 2) + Math.pow(Bangle.
getGPSFix().lat - seekLat, 2)));
    g.drawString("Distance: ", 5, 16);
    g.drawString(distance, 5, 56);
  }
}

var interval = setInterval(updateScreen, 1000);
```

This uses the GPS to get the latitude and longitude and compares them with preselected amounts. It then uses Pythagoras's theorem to determine the distance between the watch's current position and the 'seek' location.

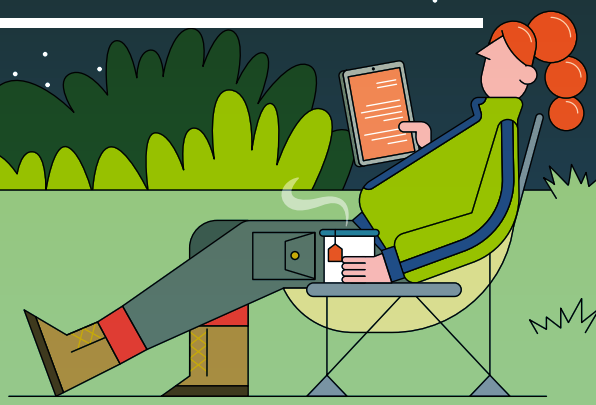
There is a slight problem with this method: we've assumed that Earth is a flat grid, but it's not, it's a sphere. While lines of latitude are parallel, lines of longitude come together at the poles. This needn't concern us too much, since the number will still go down as we get nearer the sought location, but it does mean that there is no straightforward way of converting the number to a useful unit of measurement.

ROUND IN CIRCLES

With our slightly unusual navigation app, we have to walk a little aimlessly. We have to take a few guesses and make a few wrong turns. By doing this, we experience the landscape differently. What do you think – is it a fun way of finding the way or a frustrating waste of time? The great thing about a high-tech solution like the Bangle.js watch is that if you don't like this, you don't have to use it. If you want something more precise, there are apps to follow GPX trails, display maps and more. Even if you can't find what you're looking for, with a few lines of JavaScript, you can create your own. →

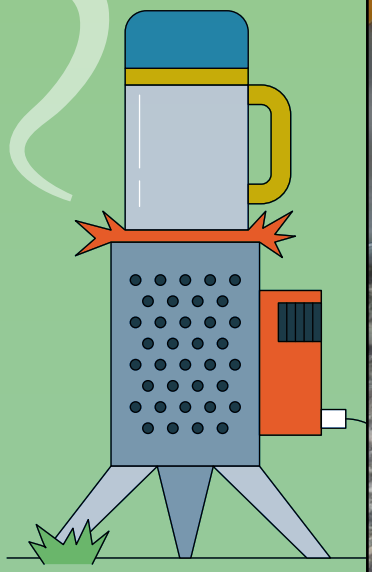
LOW-TECH

Maps and compasses are so embedded in the idea of life outdoors that they're commonly used as symbols for it. The process of mapping countries and continents was a massive undertaking. Today, we take it for granted that you can quickly and easily get a map of any location, but that's a very recent phenomenon. Nowadays you can get maps in different scales and showing different details. Once you've learned the necessary skills, a map and compass can get you almost anywhere. And it does have the one advantage that every map-wielding walker likes to remind us about – the batteries don't run out.



Fire

Stay warm and cook some delicious food



Above Right We got far less smoke from the BioLite than we get from conventional campfires

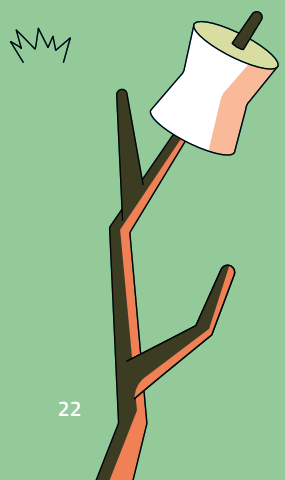
Below Right The BioLite CampStove 2+ has a removable electronics unit which includes the fan, probe, and battery

We can't quite explain our relationship with fire, but there's something primal about it. Our ancestors' mastery of fire was one of the first things that separated us from the rest of the animals. Cooking food allowed us to consume calories more easily, which then led to us evolving in ways unlike any other animal in the known universe.

We now have microwaves, electric kettles, and a wide assortment of kitchen gadgets, which means we no longer need to burn wood. However, during the last million or so years of evolution, fire has left its mark on our souls, and a campfire just feels right. But should we go high-tech or low-tech?

The peak of portable wood-burner technology is probably the BioLite CampStove 2+. This is a canister that you load with sticks. Turn it on and a fan starts blowing air into the chamber, helping the wood burn cleanly. On top of this, there are optional accessories of a kettle (with a removable cafetière plunger) and grill.

You might be wondering where the fan gets its power – after all, no one wants to have to stop a campfire because their battery's died. Quantum physics comes to the rescue. The Peltier effect is where a particular combination of materials generates an electric current when there's a temperature difference across it. In this case, there's a probe going into the fire, and when that gets hotter than the outside, a current is generated. This powers the fan, charges up the internal battery, lights an LED light, and can even charge your phone.



> Having a campfire usually means acquiring wood that's already been cut and dried

Right
Rocket stoves aren't as controllable as the BioLite, but have some of the advantages and are far easier to customise

LOW-TECH

Why do you need fancy electronics? Every good scout knows how to light a fire. Start off with tinder, build up to kindling, and finally your logs. Build up and don't forget to leave enough space for airflow. You'll soon have a roaring fire.

Perhaps the trickiest bit of building a campfire is cooking on it – there's no convenient place to put your pan. There are plenty of solutions to this, and many cultures around the world developed their own. In some places you'll find people dangling pots from tripods. In others, grills are placed over the fire. This author mostly uses a technique he learned when living on the Swahili coast.

Three large and roughly equal-sized rocks are placed in a triangle to form a stand for your pots. The wood is divided into thirds, and each third is poked through a gap between two of the rocks so they meet in the middle. A fire is lit, and then you pop your pot on the rocks. This sounds simple, but allows for a surprising degree of control. You can adjust the temperature by pushing the wood in to create a crowded centre, or pulling it back. You can – if you select the right rocks – adjust the height of the cooking pot by pushing the rocks in or out.

This sort of low-tech solution – using just things you can find in the natural environment – is the essence of the outdoors, isn't it?

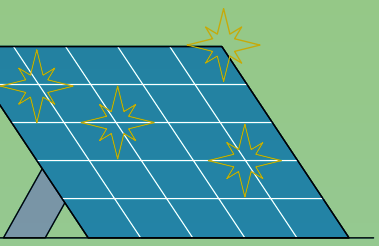
The low-tech solution here is great, but it's not without its problems. The two main ones are that it's very smoky and it uses a large amount of wood. We might have the romantic notion of heading off into the woods and gathering fuel for our evening's fire, but the reality is that it's pretty hard to find that much deadwood in most places. Having a campfire usually means acquiring wood that's already been cut and dried.

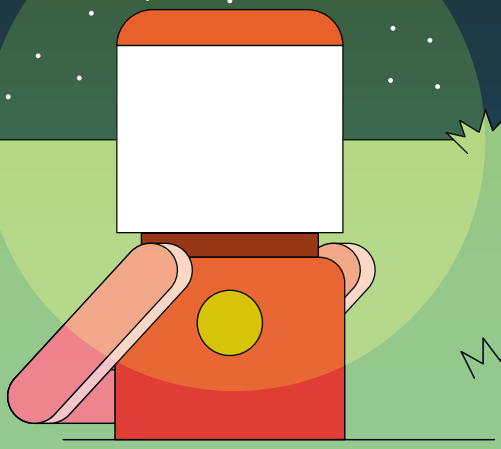
A forced-air burner like the BioLite solves both these problems. It's not smoke-free, but it does have far less smoke than a campfire, and you can use sticks and small bits of wood. Realistically, you can find enough bits in most places with trees to cook dinner and warm yourselves.

Which is best? That's a question that has a different answer for different people. However, next time we venture outside of HackSpace mag HQ, we'll be packing our BioLite stove.

MAKE IT YOURSELF

The BioLite stove works well because it gives you more control over airflow. While it's hard to DIY something quite as efficient, a rocket stove is a design that uses basic physics to improve the flow through a wood fire. There's a good overview of a metal rocket stove at **hsmag.cc/rocketstove**, but you can make a similar stove in many different ways.





Lighting

Don't stop when the sun goes down

> **Light isn't just about brightness**

Left
The state of this lantern shows just how rarely we reach for fossil fuel power in the age of LEDs and LiPos

Below
Light up your campsite with a set of glowing orbs
Credit: Erin St Blaine (CC-BY)

When it comes to modern high-tech, we have a huge amount of choice. LEDs and LiPos are now so ubiquitous that it's easy to forget that they're modern inventions – both originally coming out in the 1990s, but not really reaching the camping public until later. Older readers will remember the constant battle of batteries running out and bulbs blowing. However, we needn't concern ourselves with the past.

You may not be aware of the torch (or flashlight) subculture, but in the last decade or so, some internet users have been on a quest to get the brightest possible light into their hands. It's become something of a meme to build brighter and brighter torches, and this peaked with the Hacksmith building a monstrosity that puts stadium floodlights to shame: **hsmag.cc/hacklight**.

Light isn't just about brightness. When it comes to setting up camp, we're more commonly after ambience. This is somewhere where we makers can really get our hands dirty. If you want to get creative, Adafruit has some fantastic guides for creating glowing props that will add light and atmosphere to any campsite. A couple of our favourites are floating fireballs (**hsmag.cc/fireball**), and a burning wizard's staff (**hsmag.cc/wizard**). While these might be a bit over the top for some tastes, they give you an idea of what a creative maker can do with a microcontroller and some LEDs.

Above
Who needs a torch when you can have a wizard's staff?
Credit: Erin St Blaine (CC-BY)

LOW-TECH

If all that sounds like it's a bit too complex, then fear not. It's perfectly possible to see at night without disturbing electrons.

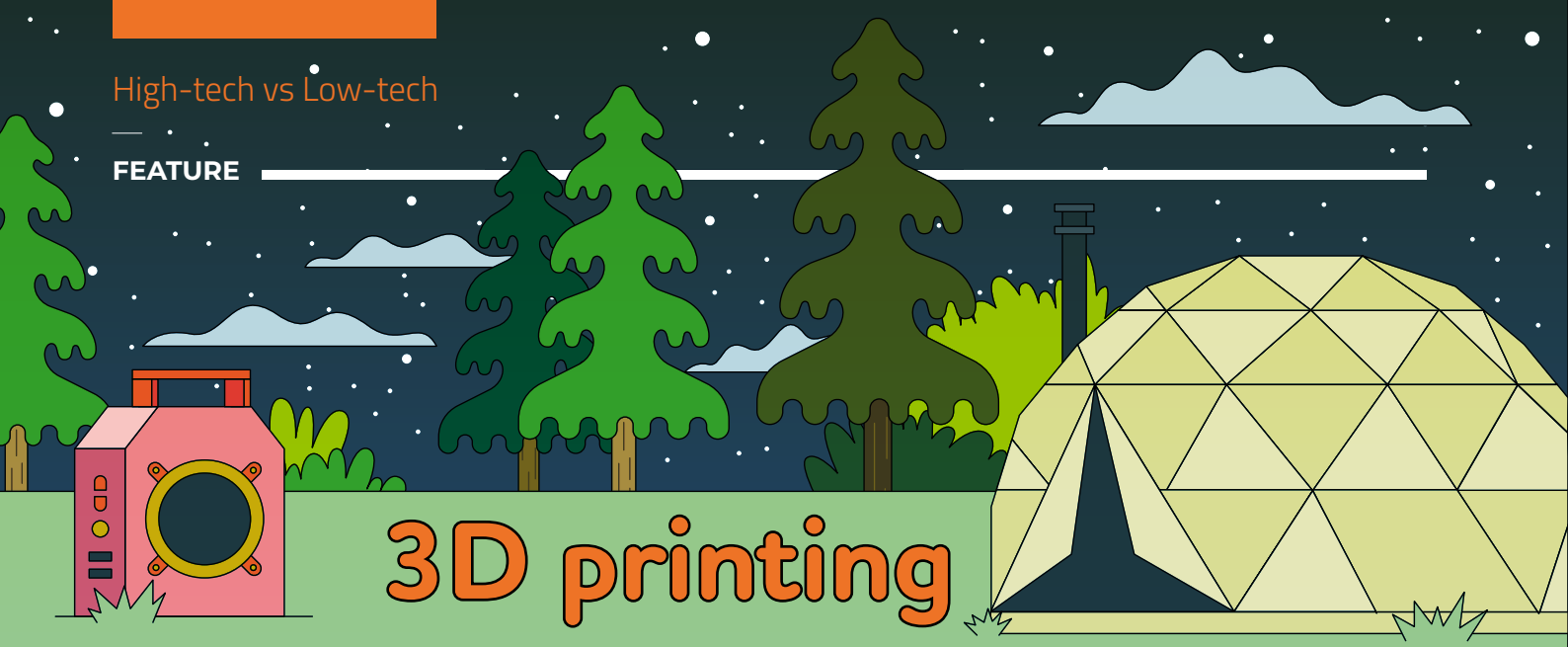
The most common form of electricity-free lighting is candles. However, in their simplest form, candles are pretty rubbish for camping. They don't put out much light, and they don't stand up to much wind.

If you want a flame outside, you will need to protect it from moving air. However, even with a cover, candles don't put out much light. In simple terms, how bright a flame can be depends on the size of the wick, and candles are limited here because heat has to melt the wax before it can be drawn up the wick – if the wick is too long, the top simply burns off. To get a bigger flame, we need to move to liquid fuels.

With an adjustable wick and a reservoir for liquid fuel, a basic oil lamp might seem about as advanced as an open-flame lantern can get. However, for a long time, this was one of the major sources of light, and plenty of engineering time went into optimising it. Flame-based oil lantern technology peaked with the cold-blast tubular lantern. These used the airflow from the flame to pull air through two pipes that ran alongside the lantern (you didn't think these were handles, did you?) before feeding this warm air safely into the flame, even during high winds.

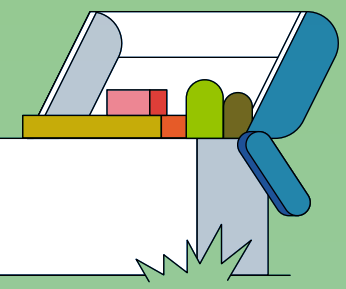
This isn't the end of the story for fossil-fuelled light, though. Pressure lanterns used pressurised kerosene (and later gas) to heat up a mantle which glows to produce a bright white light, far more similar to a light bulb than a flame. While flame-based lanterns could give a low atmospheric glow, pressure lanterns can light as well as any electric bulb.

Usually, the question between high- and low-tech isn't so much which functions better, but which creates a more pleasing effect. Obviously, this is a personal matter, but for the vast majority of people, LEDs are going to be the best solution here. They can be brighter, dimmer, flicker more, and they're easier to carry. What's more, they do this without the fire risk or smell of open flames. →



3D printing

Fabricate the bits you need for your next adventure



3D printing gives us a lot of control over the things we make, from picking exactly the colour (or colours) that you want something to be, to adjusting its size. You can even start your design entirely from scratch. Whether you're downloading existing models, or creating your own, no other manufacturing technology gives makers quite so much control over the things they build. We set up our 3D printer and created a few bits to ease our camping adventures.

Tent-pegs are one of those things that seem simple but actually are incredibly nuanced. Most tents come with bent wire pegs that work OK for ideal ground, but once you meet with reality, you very quickly find that they either bend in hard ground or pull out of soft ground. For hard and rocky ground, you want stronger metal stakes that you can whack with a big hammer. For soft or sandy ground, you want something wide, and this is an area that's badly served by tent-pegs on the market. A 3D-printable peg, such as **hsmag.cc/tentpeg**, can be scaled to be wide or long. Carrying a few different sizes means the most suitable option can be used in the most critical spot.

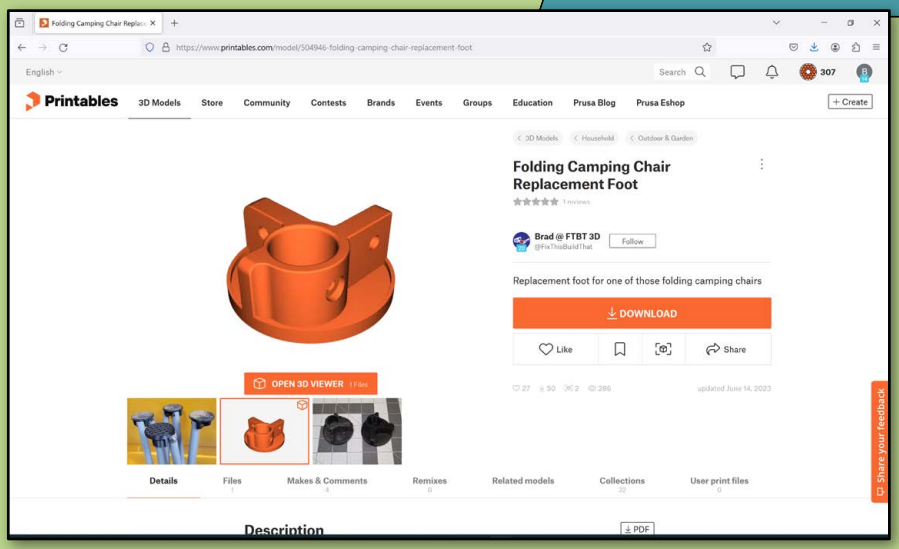
Above Right
While this is small, it does work to dig holes, and it's very lightweight

Below
Getting ready for our next camping trip

If you're going somewhere without a toilet, you're going to have to dig your own. There's a huge range of options for folding spades or trowels, but if you're travelling light – really light – you might find that none of them are quite featherweight enough. Medelis3D has designed an option that comes in at just 20g: **hsmag.cc/spade**.

Finally, if you're building a shelter with a tarpaulin, you'll probably have found that it's hard to attach ropes. The eyelets aren't always in the right place, and they're not always strong enough. Never fear, you can 3D-print yourself some tarp clips that grip onto the material and allow you to tie on rope: **hsmag.cc/tarp**.

There isn't really a low-tech equivalent of 3D printing, but we can certainly get the same basic things another way. All of these are available at outdoors shops. With 3D printing, you do get to make them in whatever colour you want, and you can also adjust the size to your exacting specifications, but is that important to you?



HIGH-TECH VS LOW-TECH

When we escape to the country, we try to distance ourselves from some aspects of modern life – the things that distract us from the world around us. Phone notifications, social media, and streaming television, to name but a few. These bits of technology can increase our mental burden and remove us from our place in the world.

However, some bits of technology can help us enjoy the outdoors as well. Some high-tech options get rid of the downsides, some let us pack lighter, some cost less, and some are more customisable. Modern isn't always better, but it's not automatically worse either. We need to assess each option on its own merits and pick the things that work best. For us, that usually means choosing the simplest solution to any problem.

As we said at the start of the article, we're not here to tell you how you should or shouldn't enjoy the countryside, but hopefully, we've given you some ideas for how you can make the most of your time in the fresh air.

Above Right
YouTuber Mike In The Woods has been putting 3D-printed outdoors equipment to the test. See the results at hsmag.cc/mikewoods

Above Left
A search on Printables suggests feet for camping chairs are a popular part for 3D printing

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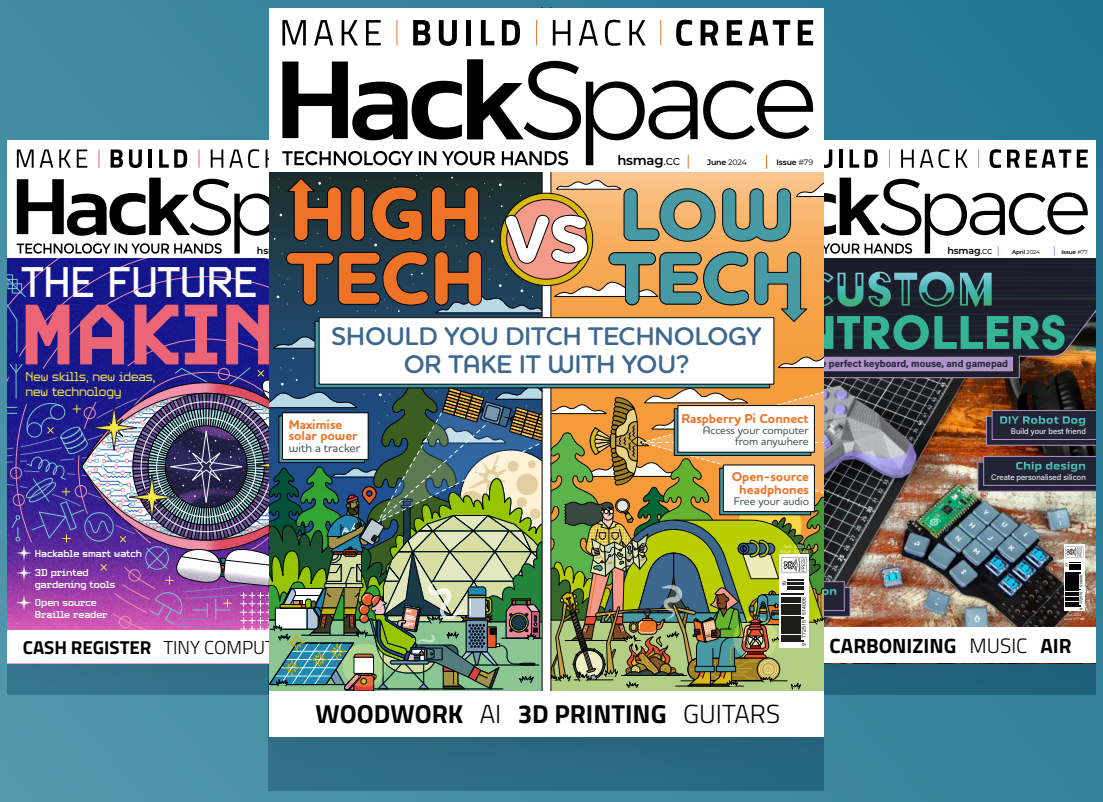

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FEATURE

HOW I MADE

DUAL AXIS SOLAR TRACKER

By **TIM RITSON**

It all started with a free solar panel. I came across it in my late father-in-law's wardrobe, so I added it to the pile of things-I-might-never-use in the boot of my car. I knew he would approve of any way I could put it to use. Little did I know that it would be the start of a project that would become a mildly unhealthy obsession, starting small, but evolving into something… well … big and heavy! But awesome!

After bringing the panel home – an outdated, 20W, 2.6kg slab of silicon and aluminium – I started to think through what I might do with it. I decided to buy a battery and charge controller, and put it in the sun… just to see how it would go. I propped it up on an outdoor chair, but pretty quickly I had to keep on moving it out of the shade and rotating it to face the sun. I had recently been looking at

Left
Capturing the first rays of morning sunshine

DIY telescopes with Dobsonian mounts – a simple device not too different to a machine gun turret. It had two axes of rotation – the barrel of the telescope, like the machine gun, could tilt up and down, while the whole mechanism could rotate horizontally through a full circle. How hard could it be to build this for my solar panel, slap a couple of stepper motors on each axis to control the rotation, and run them from an Arduino?

And so it began. There was no real purpose to save the world with super-efficient solar generation. It was just simple curiosity. To see if I could do it, and where the journey would take me. I also figured it would be a good stepping stone to that DIY telescope – as is often said, why spend a few minutes aligning it manually, when you can spend several months automating it!

POWER SYSTEM

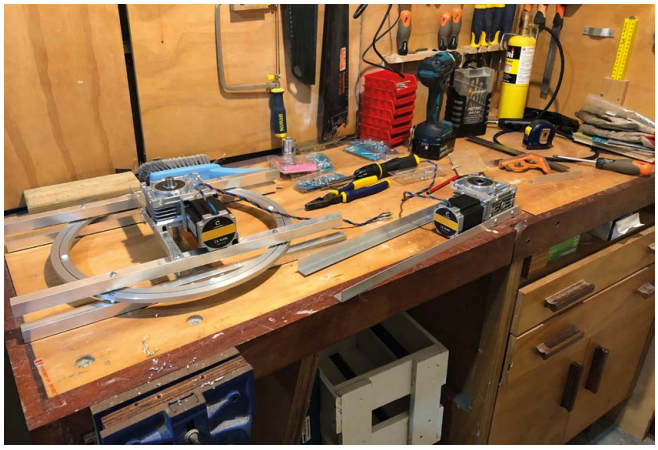
The first components I needed were to harness the power from the solar panel. My initial thought was to find an old car battery and hook it up. But, from some quick internet research, I learnt that a) old car batteries aren't that easy to find, b) aren't that cheap, c) aren't even the right type of battery, and d) you can't just connect a solar panel directly to a battery. It turns out, 12 V lead-acid batteries don't take kindly to being charged at 18 V.

Instead, a charge controller is the way to go, transforming the solar panel voltage to a suitable level for battery charging. I performed a few back-of-the-envelope calculations, and bought some appropriately sized components within my budget. And, with a little foresight, I chose a charge controller that had a USB output to provide an easy way to power the Arduino. →

MA

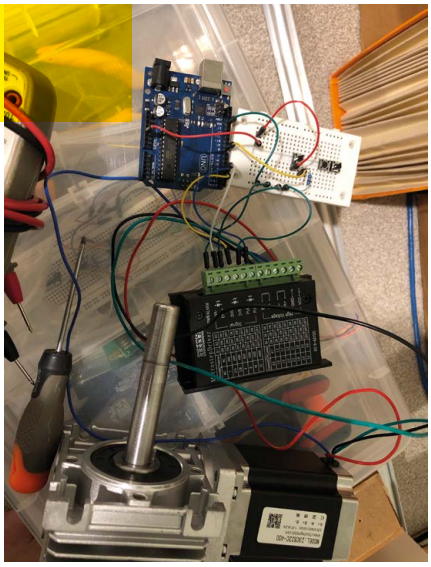
CONTROL MECHANISM

The next components needed were the motors to rotate the solar panel around each axis. I selected NEMA17 stepper motors, and 80:1 reduction gear-boxes. I had had some experience with stepper motors from a previous project (albeit much smaller and cheaper) and I liked their accuracy and 'digital' nature – they are designed to move through a discrete number of steps, so are well-suited to position control. The motors use TB6600 drivers, which receive 5V, enable direction, and step signals and move the motor one step at a time.



Above
First motor mounted

Right
Familiarising myself with the new motors



The overall mechanism is significantly overspec'd. The NEMA17 motor has 200 steps to rotate through 360 degrees – 1.8 degrees per step. However, upon receiving the motors and drivers, I hooked them up and began tinkering, and I soon discovered the drivers also allow microstepping – dividing each step into 32 steps. So the motor can actually be controlled with 6400 steps – that's 0.05625 degrees per step. Now, combine this with the 80:1 reduction gear-box, and we have a cool 512,000 steps per rotation. I figured, speed isn't an issue, so why not? The more accurate the better! In astronomical terms, a resolution of 512,000 is equal to 2.5 arc seconds – less than the angular diameter of Mars (and pretty much any planet in our solar system)! If that doesn't mean much to you, imagine cutting a cake into 512 pieces, and then cutting each of those into 1000 pieces – a very sticky mess.

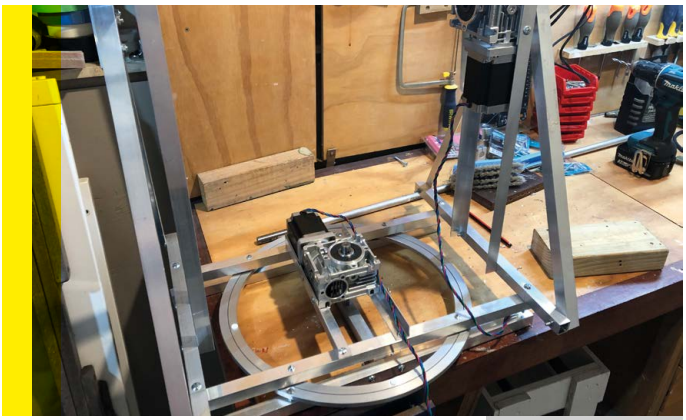
Anyway, as I would discover, other factors would constrain accuracy to be well outside of this range. And, in hindsight, it was also inefficient to use such a large integer – to encode 512,000, as you need at least 19 bits. So it required a 32-bit integer, where 16-bit would have been quite acceptable.

Below
First section complete

FRAME

In parallel with purchasing the motors etc., I was also logging into SketchUp online to create 3D models of various frame designs. This was helpful to visualise how all the parts might go together. I was limited to what I could purchase at a local hardware store – square tube and angles – and build with a relatively simple toolset – saws, drills, screwdrivers. I have tried to use aluminium as much as possible, partly to keep weight down and also because it doesn't corrode. I did experiment briefly with aluminium welding to fix the members

Below
Fully assembled



Above
Vertical sections installed

Below
It was a very tight fit getting all the electronics in one space, while also keeping connections accessible

together. However, it turns out that this is hard, and using a blow-torch to smelt aluminium on my wooden workbench in my wooden framed house, with wife and kids sleeping soundly above, just seemed like a bad idea. So, nuts and bolts it was.

One central part of the system was the rotating platform. It needed to support a significant amount of weight, while also rotating freely through 360 degrees. Initially, my research took me to some very nicely machined ball bearing housings, suitable for aerospace applications. But, having not won the lottery that week, I continued searching and soon came upon Lazy Susans – a fixture of any Chinese restaurant. Placed in the middle of a round table, they are spun around to allow the patron to serve themselves from the selection of dishes on the central turntable. A much better fit for my budget, and available from AliExpress in a wide array of sizes, I chose a sturdy-looking 16-inch version.

Piece by piece, section by section, it came together. I finally added the rotating tube to which the panel is fastened and added a counterweight to reduce the load on the shaft and motor. I needed a couple of specially machined parts for this from AliExpress, mostly designed for CNC machines. It wasn't pretty, but it was functional.

CONTROL SYSTEM

The brain of the device is an ATmega328P. Rather than use an Arduino, I wanted something more custom-built, so I designed and soldered my own circuit on prototyping board. The vital organs, if you will, are the push-buttons for manual control of the motors, a 16 × 2 LCD screen, and a Real Time Clock (DS3231). There are a number of headers for interfacing with the motor drivers, programming (USBasp) interface, USB power, ADC inputs, and additional I2C devices. Together with the charge controller and motor drivers, all this is housed in a weather-tight box – all cables enter through the bottom to avoid water ingress.

WORKING PRINCIPLE

Fundamentally, the operation is simple: the microcontroller calculates the elevation and azimuth of the sun, based on its location on Earth and the date/time, and instructs each motor to rotate until the panel is at the desired position.

First, the program also needs to get the initial position of the motors in order to know how far to rotate. Unlike servos, stepper motors are 'open loop', meaning they do not provide any position or speed feedback, so it's necessary to keep track of the motors' positions manually. This was initially achieved by manually rotating the panel (via the push-buttons) to a known position the first time the device was switched on. I then programmed it to save this position in EEPROM so that it would remember its position when power is switched off.

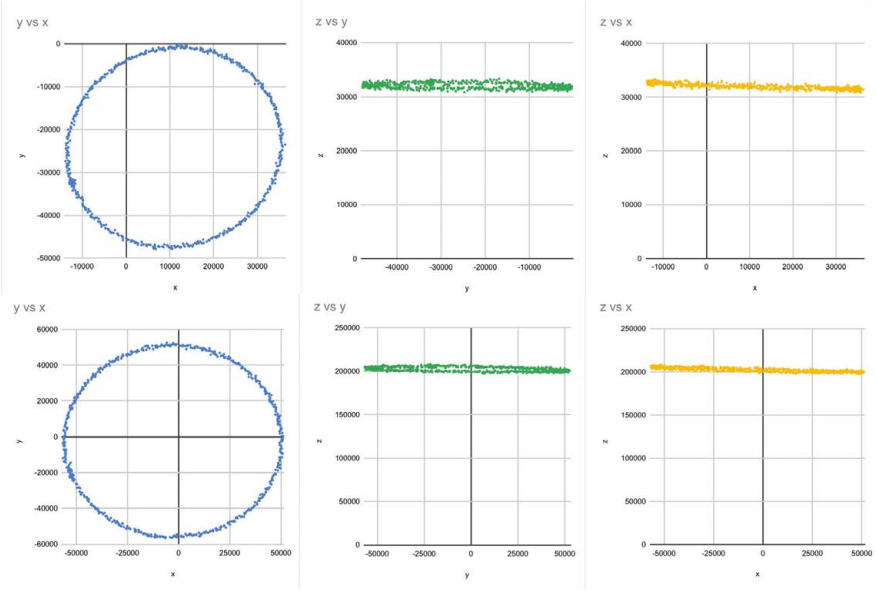
This would require EEPROM to be written any time the motors moved. For thoroughness, I even implemented EEPROM wear levelling. This is a method to avoid surpassing the rated number of write cycles of EEPROM (100,000) by writing data (the saved motor positions) to a different memory address each time.

Next, date and time is received from the RTC. Latitude, longitude, and time zone are hard-coded. Sun position calculations are based on David Brooks' open-source code from 'Arduino Uno and Solar Position Calculations (dated Feb 2015), **hsmag.cc/SolarCalcs**. I'd like to say I developed my own calcs, however, I believe in standing on the shoulders of those who came before us (and also because I didn't have time to get a degree in astronomy).

A timer interrupt was used so that the program would periodically wake, calculate the sun position, and then rotate the panel. I typically set this to happen every 60 →

Right
The three-axis magnetometer, located as far as possible from sources of magnetic interference

Below
The uncalibrated magnetometer readings. The azimuth is calculated via arctan (x,y), effectively drawing a vector from (0,0) to a given point



Above
After calibration, the blue circle is centred at (0,0)

"THE PROJECT HAS BEEN A CONSTANT LEARNING EXPERIENCE"

seconds. However, this can be set faster. Another method would have been to constantly rotate the panel at a controlled speed. However, this would require more complex calculations to time each motor step – the speed of each motor would be different and vary constantly throughout the day.

Each time the program wakes, it must also check if the sun is actually up, i.e. if the time is between sunrise and sunset. Sunrise and sunset times are calculated as part of the sun position calcs, as they differ throughout the year and by location.

When night-time is reached, the code changes to 'night mode', whereby it rotates the panel to the starting position for the next day, and waits, patiently, until the sun rises again.

SENSORS

Most recently, I have added two sensors so that the system can measure its own position. This makes the manual calibration process unnecessary. I installed a magnetometer (QMC5883L) to measure azimuth (effectively a compass heading) and an accelerometer (MMA8452Q) to measure tilt. When first received, the magnetometer didn't work well. I realised it needed calibration. The Earth's magnetic field is weak, so the magnetometer is sensitive by necessity. However, this means it is susceptible to external magnetic fields. With a large lead-acid battery and two DC motors nearby, it wasn't exactly an ideal environment for it. So, I placed it on top of the frame, as far away from these as possible, and calibrated it in situ.

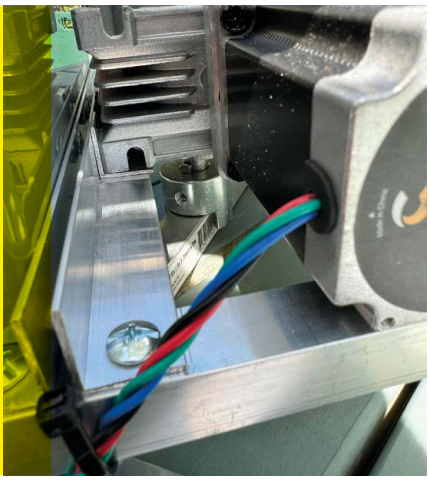
Edward Mallon's blog post was a godsend for figuring this out: **hsmag.cc/EMallonCavePearl**. This explained the process to plot X and Y readings from the magnetometer (and Z too if needed), which trace out a circle as the magnetometer is rotated. The circle's centre should be at 0,0, and the circle should be round. They were way off initially, so I used a free piece of software (as explained in the blog) to calculate a set of corrections that are hard-coded into the azimuth calculation.

CHALLENGES

The project has been a constant learning experience, discovering issues and figuring out solutions as I go. The first problem was a reminder that aluminium is soft. The shaft from the azimuth motor is fixed into a square aluminium tube in the base. The shaft has a key, and I cut a corresponding notch into the tube. However, after a while of operation, it fully reamed out the hole.

Luckily, I had a spare part made of steel that fitted over the tube snugly and had a properly machined key. I also found that the movement of the panel was jerky. The heavy panel is fastened directly to the rotating tube, so there is almost no leverage, causing it to wobble easily. To mitigate this effect, I programmed the motors to ramp speed up and down gently when starting and stopping, smoothing out the jerkiness.

In hindsight, I would build this differently next time. Perhaps using a freely rotating shaft, controlling the pitch via an arm attached to one end of the panel. I also noticed that there is quite a bit of play in the gear-boxes, a bit like a loose steering wheel on a car. When the motor driving the gear-box is rotating in one direction, the output shaft rotates correctly, but when the direction of the motor is reversed, the output shaft is loose and doesn't engage immediately.



Above ↗
The part I used was a bit of a hack – half of a shaft coupler that just happened to snugly fit over the square tube

Left ←
The damaged hole in the soft aluminium square tube caused by the shaft key

To overcome this, I measured how much play there is, and programmed the motor so that when it changes direction, it moves through an additional few degrees to engage in the reverse direction.

Unfortunately this is a case of 'you get what you pay for'. Gear-boxes with the accuracy I had hoped for would be a great deal more expensive. The program is also nearing the memory limit of the microcontroller. I first noticed this when I wrote a function to simulate one full day of movement. It calculated position data for every few minutes of a day and saved it into an array. I had to reduce the size of the array or the program would crash. I also discovered that text strings use a lot of memory.

Above ↑
The 'finished' product

So, all the serial debug messages and LCD output strings were using up the majority of available program space. I eventually implemented some preprocessor code (e.g. `#ifdef DEBUG_ENABLED #endif`) so that debug messages wouldn't compile unless explicitly enabled in code.

CONCLUSION

No project is ever 100% complete, and this project is no different. I still plan to measure the power generated by the solar panel, and possibly the power drawn by the tracking mechanism. By comparing the two and checking against a non-tracking scenario, I will find out if this has actually achieved anything at all – that is, does it generate more power than it uses by rotating to track the sun? It doesn't really matter either way – I now know so much more than when I started. I've learned a lot of technical skills, learnt some lessons, but also that I can achieve a lot by breaking a problem down into manageable chunks and working through it. I will certainly need this patience for the next stage – building a telescope! □

HackSpace magazine meets...

Jón Schone

Beware: this man does weird things with 3D printers

It's easy to crack a joke; it's hard to write a love letter. That's why we admire Jón Schone so much. While there are a few YouTubers seem to reduce 3D printing to a joke, Jón clearly loves it. Every video he makes, every device he builds, is a genuine attempt to learn something new. He does things with 3D printers that you shouldn't be able to do, such as printing car wheels. He uses materials that most of us wouldn't even think of, such as Kevlar. And like the engineer that he is, he gets things wrong until he learns how to do things right. If you're not aware of his work go right now to **properprinting.pro** and have a look at some of Jón's work – then come back here and read what makes him tick. →

Below
Jón Schone, having another lightbulb moment with his 3D printed gantry system

HackSpace Morning Jón! One thing that stands out about your videos is that you're doing proper engineering, which is rare to see – 3D printing can be a joke so much of the time.

Jón Schone And that's weird, because 3D printing is such a good fit for doing engineering. To be honest, I do see a lot of actual engineering being done with 3D printing, but not in the consumer space or on YouTube. I've seen it a lot when I was still at work. I quit my job almost a year ago, but I had worked for an electronics manufacturer for eight years. We used 3D-printed tools to help with production, and it was always something functional or mechanical. In a professional environment, proper 3D printing is pretty common, but you don't see it very much on YouTube. That's something that I want to show.

HS Are you doing YouTube full-time now?

JS Yes, since May last year. It was quite a step. But I live alone, I don't have family, my cost of living is quite low. So I thought, well, this is the moment where I can make the jump. If I need to eat potatoes for a month, it's only on me. So I went for it.

HS How did you discover 3D printing?

JS That was almost ten years ago now, when I worked at Philips. I was there as a test engineer in the shaver department. We got the small PCBs to test during the development process. And we did lots of automated testing.

Back then, they were placing the first UltiMaker machines (the wooden ones), across the whole site just to play around with. At the time everyone was just printing decorative things like an owl or the Eiffel Tower, that sort of thing. And I was working on a test jig with four shavers next to each other. And they had to run charge/discharge cycles in parallel, and we had to measure the RPM and everything. I already had some CAD experience, so I made something quick and dirty, and printed that out. And I think that I'm among the [first few], maybe even the first, at Philips who used 3D printing for the production process.

That's where it started. It's awesome that you can have a specific problem and a couple of hours later, you have your physical solution. That was the spark.

HS And you were a machinist before that?

JS When I was 15, I went to a school for precision mechanics. I finished that when I was 19. I wanted to go further, so I started a Bachelor of Mechanical Engineering, but that was too broad for me – there was a lot of practical maths on bridges and larger structures and that was not my thing. I ended up at another electronics manufacturer, which offered me a Bachelor of Electrical Engineering. Most of my working hours were as an electronics engineer, but with all my jobs there has always been some element of mechanical engineering there, because we needed some stuff made. So I never lost my passion for mechanical engineering. I don't like making the calculations, but I do like coming up with the idea and coming up with solutions.

> "You aren't wasting expensive machining hours or expensive materials"

That's another reason why I like 3D printing so much: you can get away with just trying things out. You aren't wasting expensive machining hours or expensive materials. You don't have to make dies for injection moulds and all that stuff, so the risk is quite low. So of course, it depends on the application. But most of the time when I build stuff I just design it and see if it breaks, so I find out in the real world instead of doing all the math. On one hand that makes you a lazy engineer, but on the other hand, you can come up with far more creative ideas much faster.

HS A background in mechanical engineering makes a lot of sense. The gantry system that you made, with the cable running through a 3D print to provide tension, that looks very much like a bridge. Where do you get your ideas from?

JS That's a good one. When I started my YouTube channel, I didn't have a lot of ideas. But I always try to solve a specific problem. With my first video, I ran into the problem that it wasn't easy to get to the hot end of a 3D printer. And I was looking at my tripod, how the camera was connected and disconnected. I thought maybe I could combine the two and make some kind of tool change system.

That was my very first idea, and that led to different ideas: if I can replace the tool, then maybe I can place a laser cutter on there or a grinder. And that's what I always tried – just set myself a specific problem, and then see if I can solve that problem. And on my way, I run into different problems. That's what I try to convey: because I think that quite a lot of people are, not afraid per se, but don't like making mistakes.

But my motto is that if you make a mistake, then there are two outcomes: you come up with new ideas, or you learn new stuff.

Sometimes it can be something mundane; taking something that already exists and seeing if it can be replicated using 3D printing. That's where the idea of making a car wheel started. Initially it's a very simple thought of like, OK, can we make a car wheel using 3D printing? So that's the initial problem. Then you find yourself a way to get there.

So the first problem is that it's big, so I need a big printer. The second →

Below
Getting an FDM printer to use resin was a huge technical challenge, but Jón did it. We're not sure why, but he did it

Above
Jón made an extruder out of that other great maker material: laser cut plywood

problem is that because it's so big, and I want stronger materials that are prone to warping, I have to make some sort of heated environment to print it. But the printer I used was a bed slinger; it was a huge bed slinger with a 500 by 500 millimetre build plate. So, if I want to make an enclosure for it, it should be at least one metre deep, which is way too big.

So then I fixed the build plate and let the portal move back and forth. I didn't know that I'd end up solving these problems when I set out to make a car wheel, but along the way, I ran into these specific issues and tried to find solutions for them, and that resulted in more and more new ideas. That's what I try to show on the channel. I show my failures because some ideas are just stupid, but I want to figure out what happens if you try anyway. And if it fails, then I've learned something.

HS Did you ever drive the car with a 3D-printed plastic wheel?

JS Yes, in the backyard. It was a bit anticlimactic because I had the idea that we would just floor it and the rim would break and you'd see a load of plastic flying around. I thought it would make a hell of a video. But it was anticlimactic because it just held – it was just me and my friend driving around. So it was a success, but on the other hand, sort of a failure because I wanted it to fail.

HS You use a lot of quite unusual additional materials in your prints. The common ones would be brass rods, say, but you use Kevlar and carbon fibre and stuff. I think of that as being quite high-tech, but am I wrong? Is that sort of stuff available to the everyday maker at home?

JS Yes, it's actually surprisingly easy to get your hands on. The Kevlar fibre I got from a Belgian company that I found online. I found the Dyneema wire on Amazon, and the carbon fibre rods from Conrad – those are often used for guides, if I'm not mistaken. But yeah, it's pretty cool that as an average consumer, you can get your hands on these high-end materials.

I did make the mistake when I started the channel that I was buying stuff from b2b companies, like RS Components and Farnell and all that stuff. And then I found out that people weren't able to replicate my printer modifications … so now I try to source parts that are also available to the average consumer, because that makes things much easier to replicate… but still, as a consumer, you can get your hands on a whole lot of cool stuff.

HS Could you tell us a bit about TIME?

JS Yes! TIME is True Independent Multiple Extrusion. I came up with the name and realised that the acronym spells TIME – I'm pretty proud of that. The idea started with previous ideas – I don't think I would have come up with this project if I hadn't tried to print the wheel for a car. Because with the car wheel, I needed the portal to move back and forth.

> "My idea with this printer is to experiment with combining weird materials"

And that sparked the idea for this printer to have a moving portal. And then a pretty straightforward next step would be to add multiple of these portals.

And it sparked with the grill plate project – my mother gave me a teppan-yaki grill plate that she didn't have any use for, and I thought it might make an interesting heated build plate. So I thought, what the heck, let's see if I can control it with a 3D printer controller. That was actually pretty simple. And that shape of the grill plate lent itself to adding multiple portals, because it's long.

What I like about this printer is that I have the full design, so I can try my own experiments with it. My idea with this printer is to experiment with combining weird materials.

So you have, of course, multi-tool machines that can combine multiple colours of filament and, if you have a system like the Prusa XL which can actually switch between tools, you can combine normal materials with TPU, which is already pretty interesting.

But with TIME, I want to combine three main types of materials. One of them is the regular polymers. The second one is liquids and pastes. And the third one is fibres and wires. Regular polymers are just like normal 3D printing. The liquids and pastes are, for instance, resin. I don't know if you've seen my video about FDM resin printing, but I use a non-pulsating peristaltic pump to pump resin through a nozzle and use blue lasers to cure the resin, to see if it's possible to do FDM printing with resin.

I want to investigate that further, to use pastes like resin and also to see if we can combine this. For example, with pastes and liquids, we should be able to print a regular polymer and place glue between the layers… or maybe add ceramics or concrete as an infill to make parts stronger, maybe even stiffer. I want to try to dissolve polymers in a solvent to see if I can just pump the soft polymer to see if that can improve layer bonding. And I think that with this printer, it would also be possible with other printers, but this printer makes it convenient for me to combine these multiple materials. So there's a long road ahead still.

HS Is the TIME printer finished now?

JS One of the portals is not as good as the other one, because the first →

one needed some improvement, but it was good enough, and I implemented those improvements on the second one. I just received a new linear rail because the linear rail I used was running terribly. I think the results I got weren't that great because of the stretch in the timing belts over that whole length, in combination with the linear rails not going smooth. So I have better linear rails. And then, in principle, the mechanics are finished. It's not finished in a way that it can be a product that can be sold, because it's just too experimental.

But, in principle, it works. Now I can focus more on the software side of things and do the experiments I want to do. So I'm really looking forward to making a video where you can see a thumbnail of a plastic part with a concrete infill.

It's going to make it easier to create videos that have a curiosity gap. What happens if we print Loctite between layers, for instance? I'm really looking forward to exploring these use cases. What I like about having a YouTube channel is that I can do this together with my audience. I've shown some use cases, now what can you come up with? I think that with the hive mind, we can come up with some crazy stuff.

HS What are you working on at the moment?

JS In a few hours, I'm going to publish a video where I upgrade the Creality K1. That's the flagship printer from Creality that supposedly should have been very fast, and I had some issues with it with severe under extrusion. I modified it in such a way that you can add your own extruder to it.

The reason being is that this printer became a glorified paperweight for me, which was a shame because I want to use this printer to print my prototypes – simple prototypes, just print and see if it fits, usually just using white PLA because you can write on that with a pencil. So if you want to modify things, you have almost like a 3D notepad.

I want to use that printer to print these fast parts for me, and I also saw that a lot of people are experiencing issues like this.

Then I've got another fun project: I'm going to make a soundproof cabinet for my computer because I made a mistake. I upgraded my PC, it became a bit too hot and I bought the loudest fans you can possibly get, and it's driving me crazy. I saw an opportunity where 3D printing could be very interesting. So that would be my video for next month. And then the printer comes back, I'm going to Open Sauce in June – I bought a huge Pelican case. The idea is to bring the TIME printer to San Francisco to Open Sauce and see if we can print something there.

I know already that we will run into problems: they have 150 V electrical outlets over there, and with an 1800 W grill plate, that's going to be a challenge.

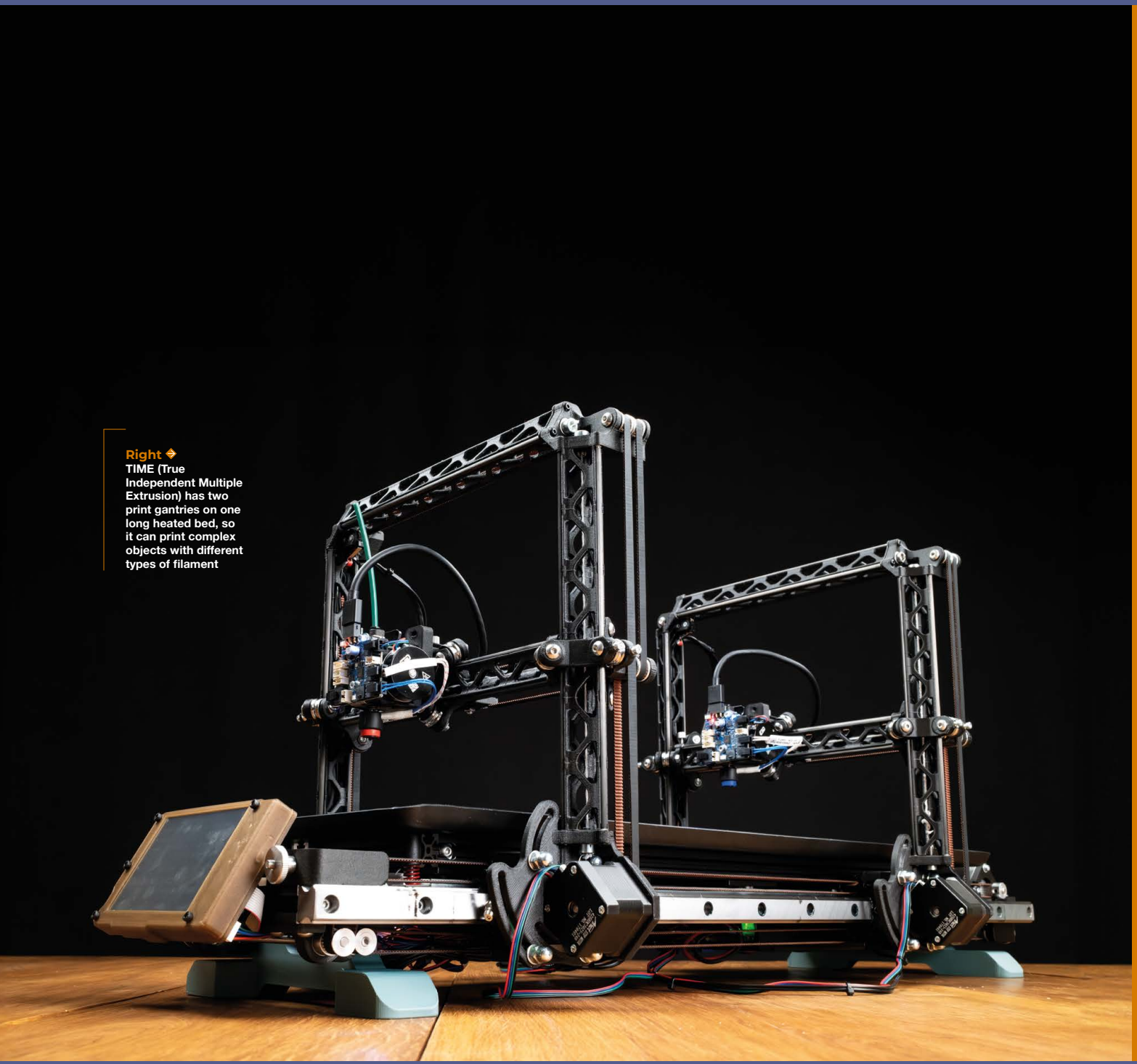
> "I've shown some use cases, now what can you come up with? I think that with hive mind, we can come up with some crazy stuff"

After that, I'm going to 3D-print shoes. If I look at 3D-printed shoes, you have these two standard paradigms: one is very futuristic shoes, and the other group is something like Crocs. But I want to print classy gentleman's shoes. And I want to use some interesting materials. I am going to use the TIME system for that because the portals can be tilted at a 45-degree angle. And I think that that angle would make it very convenient for the shape of a shoe. It has three requirements: one is that they should look extremely good, so if you go to a job interview, you get the job right away because of the shoes. The second requirement is that if you walk on a hard floor, you should be able to hear that typical clacking sound. And the third one is that they have to be comfortable.

Each of these requirements has its matching material. So the looks I want to achieve with wood – I found a material that's pretty much flexible wood, so the top will be printed out of that. Also, with that filament, the colour can be darker or lighter depending on the print temperature, so I can create some kind of gradient in the shoe that looks like the patina of leather.

The comfort will be done with an insole printed out of a material that will foam depending on the print temperature. So I can print the sole a bit softer on the front and a bit firmer on the heel by modifying the temperature. So, that's a very straightforward or convenient technique with the portal being at a 45-degree angle. And the clacking sound – it sounds a bit superficial, but it's actually a challenge because you don't want to lose grip. One of my Patreon supporters came up with the idea of using PETG with rubber inside. It's from a Swedish company, so I reached out and they sent a spool. And that looks very promising. It's firm, but it looks like it has plenty of grip. So I want to use that material for the outer sole, and hopefully try and match these three things into the shoes.

And the best thing of all is that I'm Dutch, and I'm 3D-printing a wooden shoe, which is very Dutch. ◻



Right
TIME (True Independent Multiple Extrusion) has two print gantries on one long heated bed, so it can print complex objects with different types of filament

Objet 3d'art

3D-printed artwork to bring more beauty into your life

Here's an unusual one: a 3D-printed object that's mostly not 3D-printed. This is the Älgen (pronounced very much like the English word 'alien') guitar, made by Cambridgeshire-based guitar maker and 3D printing enthusiast Michael Dales.

The central portion of this guitar is a relatively familiar chunk of walnut, topped with a rosewood fingerboard. It's the rest of it that we're interested in, though. The two halves of the body on either side of that central piece of wood are printed out of nylon, and secured to the neck with an ingenious combination of sliding dovetails and bolts running into the wood. Michael has gone into great detail in his blog in which he documents the process of making the Älgen, and even this small area is ripe for loads of tinkering. We can only imagine what it's like to painstakingly cut a dovetail notch into your project only to discover that the 3D-printed part has shrunk and you have to do it all again…

But wait! That's not all. The bridge is held onto the walnut portion using a 3D-printed assembly, and the headstock is a custom 3D-printed aluminium piece designed by Michael to keep the weight down. Rarely can we say that something is unique, but this guitar absolutely is.

hsmag.cc/Algen

Letters

ATTENTION ALL MAKERS!

If you have something you'd like to get off your chest (or even throw a word of praise in our direction), let us know at **hsmag.cc/hello**

THE FUTURE

While I read with interest your article on the future of making, I can't help feeling that it somehow missed the point. We are makers; we make things. Sometimes those things are physical, and sometimes they're a little more intangible.

We should be bold with our ambitions. The question shouldn't be what future will be thrust upon us makers – the question should be what future will we make. If you want the future to contain open, hackable hardware, then make it. If you want the future to contain upcycled and recycled goods, then make them. Let's not passively accept what's happening; let's craft the future we want.

Macy
Coventry

Ben says: Well put. Individually we're at the mercy of global commerce and megacorporations, but together we can change the world.

SANJAY MORTIMER

I went to school in an era when people who struggled in a classroom setting were labelled 'trouble-makers' or 'a bit dim'. I saw brilliant, creative minds being pushed away from knowledge that they would have been able to use in ways unimaginable to the likes of me. As well as the individual damage that's done by a system like this – countless lives not lived to their full potential – there's a loss for us all. We don't get to enjoy the works that these creative minds would have built had they been given the space and opportunity to excel.

I've not set foot in a classroom for 30-odd years, so can't say for sure what it's like now, but seeing organisations like the Sanjay Mortimer Foundation really gives me hope. The more types of thinking we allow to flourish, the richer all our futures are.

Dave
Dover

Ben says: It's been a while since I, too, stepped into a classroom as a pupil, but I have some experience as a parent. Progress is being made and differences are more acknowledged now than ever before. However, there is a huge distance still to go, and many children are still treated like square pegs being forced into round holes.

KITS

In my youth, I learned a lot from building kits. Back then, if I recall correctly, the choice was mostly limited to radios. The joy when plugging in those strange in-ear headphones (that only seemed to exist in crystal set radio kits), and adjusting the variable capacitor (that also seemed to only exist in crystal set radio kits), then hearing a voice or music!

Much as I loved those kits, I wish I'd had the range of options that you looked at in issue 78. Hopefully, this means that kids growing up nowadays really get the chance to get bitten by the engineering bug.

Richard
Middlesbrough

Ben says: I remember those in-ear headphones. They always reminded me of stethoscope earpieces. I suspect that they had a specific impedance that was particularly useful for crystal radios, but I don't know.

CARDPUTER

That Cardputer is so cute. I want one. I don't know what I'd do with it, but I want one. I think it's because phones don't have real keyboards any more and I miss my BlackBerry. I know that it won't be the same thing, but it's a bit closer to the thing than any of the modern phones. Down with blank rectangles, let's get our keyboards back.

Owen
Wrexham

Ben says: I never had a BlackBerry, but I know exactly what you mean about buttons. It just makes me a bit sad that the mobile phone market is so locked into two almost identical OSs. Apps like WhatsApp are basically essential for many people, so if you want to interact with the modern world, you have to have one of these two systems. There are so many possibilities, but a closed system means that we can't explore them.

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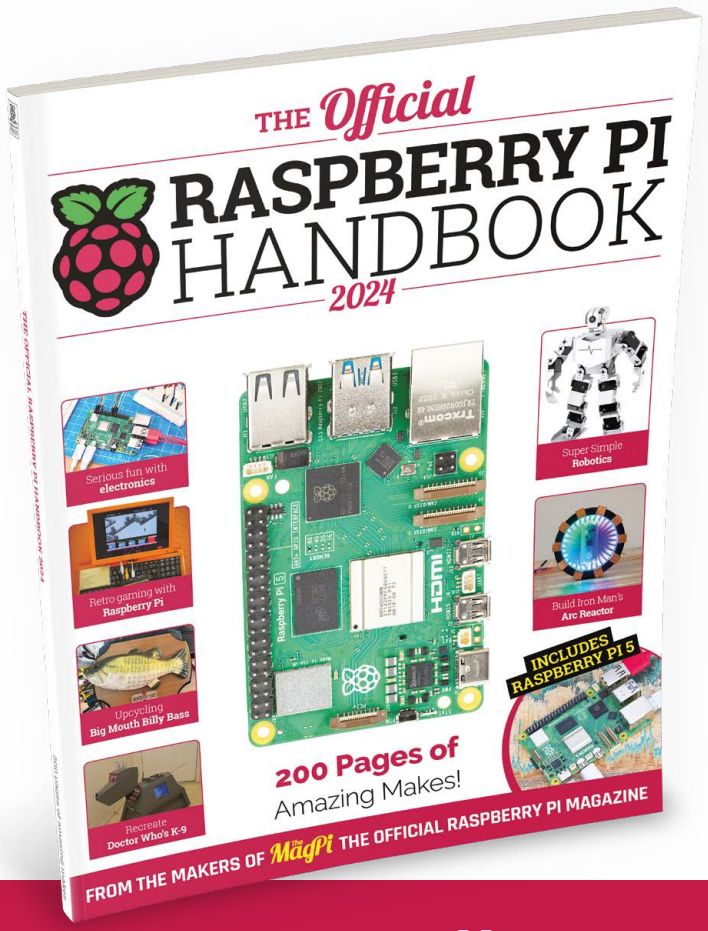

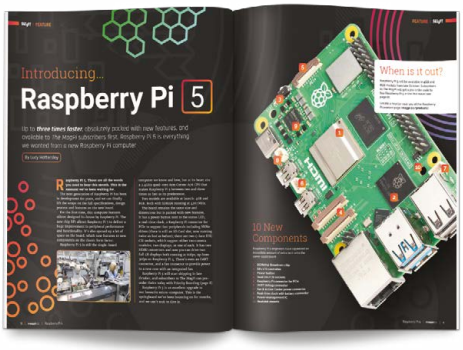

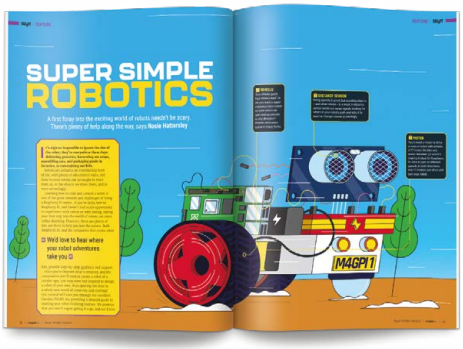

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Air dry clay – a versatile modelling material

Get your hands dirty

Nicola King

Nicola King is a freelance writer and sub-editor. She's currently de-stashing some of her craft supplies, and it's looking like she might actually be able to see the floor in the office very soon!

If you've ever wanted to try your hand at creating some simple pottery, but were put off by the high cost of entry, read on. Experimenting with air dry clay could be the answer – no expensive potter's wheels or kilns required… the clue is, after all, in the name. Air dry clay is a water-based clay so, when exposed to air, it will dry out and cure as the moisture within it evaporates. An accessible, inexpensive, adaptable, and non-toxic material, it's easily mouldable and you can blend colours. Best of all, sculpting, smoothing, and manipulating clay is such a mindful and relaxing pursuit – a sensory activity that those of all ages can benefit from.

Before we move on, three key points should be noted. Firstly, air dry clay is not food-safe, so we can't use it to make functional food-carrying items, only items for other decorative purposes. Generally, stoneware and porcelain pottery clays, once fired and glazed, are considered to be the most food-safe of clays. Secondly, while air dry clay allows you to completely skip the kiln and the meticulous drying and firing times you need to plan when using a kiln, be aware that you will need to allow plenty of time for the air dry clay to dry once you've made your piece. As slow drying is best to avoid cracking and warping, air dry clay usually takes 24 hours to dry to the touch, but 72 hours to dry completely. Bear in mind that

> **As slow drying is best to avoid cracking and** warping, air dry clay usually takes 24 hours to dry

Left
A selection of our air dry clay 'casts'. Considering these were made from something that initially resembled a block of mud, we were pretty happy with the outcome. We'll make some of the smaller shapes into brooch pins and pendants

drying times are also affected by the environmental conditions that you are working in, the thickness of the piece you have created, and the overall size of it. Thirdly, you really don't have to buy a clay modelling tool set to get underway – hacks include using items such as the end of a thin paintbrush, small sticks from the garden, pencils, straws, or lolly sticks to shape your clay – be inventive, there are no rules. Remember too that your hands are the ultimate tool when working with clay.

In this tutorial, we are going to take a look at a couple of easy and quick air dry clay projects that will hopefully leave you wanting to make more. So, let's get cutting, moulding, and shaping… →

A POTTED HISTORY OF **CLAY USAGE**

Clay is recognised as the oldest known ceramic material. Its defining property is its plasticity when wet – you can stretch it out without it breaking or tearing – and this is due to its high content of clay minerals. Clay is highly mouldable – a hands-on material which, when you have time to literally potter about with, can bring a great sense of mindfulness and stress relief. (Additionally, manipulating clay is also a great way for children to develop fine motor skills.)

When fired or thoroughly dried out though, clay hardens, and it's this attribute that has led to it being used for making pottery for thousands of years. Once our ancestors discovered that clay could be formed into objects, and then fired to produce useful items, the pottery industry was born, with techniques evolving and improving over the centuries. Culturally, pottery has played an important role in the traditions and rituals of many societies throughout history. Some of the earliest pottery sherds found have been dated to around 14,000 BCE, and were found in Japan. Ancient civilisations used clay to make containers for water, grains, and cooked food, objects of art, as well as tiles and bricks. Clay tablets found in Mesopotamia are thought to be one of the earliest writing media. The ancient Egyptians made wine and water jugs, bread moulds, and lamps among other things, adding decorative illustrations and motifs to their handiwork before, during, and after the firing process. The ancient Greeks were renowned for their pottery too, particularly vases.

It's not known exactly when the potter's wheel was invented, but it may have been around 3500 BCE, and early wheels were slowly turned by hand or foot. Over the centuries kilns, furnaces, and glazing techniques have all developed, and mechanisation has obviously enabled mass production.

However, one fundamental thing that really hasn't changed, and which connects us to the past, is the ability we possess to use our hands to build clay pieces and, as someone who once had a weekend job many (!) years ago at Poole Pottery where she watched expert potters at work, this author certainly appreciates the artistry required to create a sellable exquisite ceramic item.

YOU'LL NEED

- **Air dry clay** (hsmag.cc/AirDryClay)
- **Clay modelling tools set** (optional) (e.g. hsmag.cc/ClayTools)
- **A craft knife**
- **Clay/cookie cutter(s)**
- **Pre-made 'slip' if attaching clay pieces** (see box)
- **A craft rolling pin** (hack: something cylindrical such as a dowel or barrel of a pen)
- **Scissors**
- **Superglue**
- **Water**
- **Fine-grain sandpaper** (hack: nail file/emery board – handy for small nooks)
- **Acrylic paint**
- **Acrylic paint brush(es)**
- **Sealant/glaze**
- **Paper towel**
- **Texture wheel** (hack: search your home for textured items)
- **Images to transfer** (optional)
- **Hemp/string for hanging** (optional)

PROJECT ONE: TERRACOTTA AIR DRY CLAY OIL DIFFUSER

For this project, we used a terracotta-coloured clay (**hsmag.cc/TerracottaClay**) for the rustic aesthetic appeal. The first step with any air dry clay project is to condition the clay – by that we mean that, when it's fresh out of the pack, you need to make the clay pliable in order to work with it. Knead it and manipulate in your hands for a few minutes to get it ready to work with and to remove air bubbles. Next, roll your clay out to an appropriate, consistent thickness, such as 5 or 6 mm (bear in mind that the clay will shrink slightly as the moisture evaporates). We used a few old bathroom tiles to work on – it's a great surface as you can easily move the clay around, it won't stick too much, and you can leave your work on them to dry out.

Now you need to decide on the imprint that you want on your piece of clay – think about what you may have lying around that you could use, or use a leaf or sticks from the garden – the possibilities are numerous. How about a piece of textured fabric such as lace? We used a texture wheel and gently rolled it over the piece. Then, cut out your shape (we used a round cookie cutter). Use a little water or slip to smooth the edge with your finger to neaten it. Use a drinking straw to cut out a small hole at the top. Your work then needs to dry for a couple of days. We won't be sealing this project as it's the porous nature of the clay that we want to employ here.

When dry, sand down any rough edges with fine sandpaper (always wear a mask when sanding clay). Then, cut a length of cord and thread through the hole. We added a wooden bead and then tied the ends of the cord. Finally, add a few drops of an essential oil to the back of the piece, hang it up, and enjoy the aroma. →

QUICK TIP:

Air dry clay will crack if not dried evenly. Try and keep the thickness of your piece consistent, maybe 5 or 6 mm. Also, be aware it can be very brittle, when dry, if you roll it too thinly. Although not as strong as kiln-fired ceramics, it's still pretty durable.

Left (opposite page)
You could hang these in the car or give them as gifts. The porous nature of the clay means it will hold onto the scent, slowly releasing it into the air. The scent will last for a few days, so refresh when necessary

Above
A clutter of cutters which were purchased (cut-price) online. We didn't try this, but you could put some cling film/plastic wrap over the clay and then press down with the cutter, which apparently gives lovely rounded contours

QUICK TIP:

Working with clay is hands-on and messy! Protect your surfaces and wash your hands regularly to avoid getting dried bits of clay on your progressing work of art. Also, wash your tools as soon as you have finished to avoid ruining them with hardened clay!

TYPES OF CLAY

In its most basic form, many people visualise clay as a naturally soft and earthy substance, and most clay minerals form over thousands of years, where rocks are in contact with water, air, or steam. There are, however, several different types of clay, with a few discussed below, including pottery and modelling clays:

- Earthenware clay – one of the most common and oldest-used types of pottery clay, it's sticky with a high plasticity and is easy to work with. Mainly composed of iron and other mineral impurities. It's normally fired in a kiln. Terracotta is an earthenware clay, and needs to be glazed in order to be made watertight.
- Stoneware clay – a pottery clay with high plasticity, it's highly durable and versatile, and is often used for cookware and bakeware. Not as porous as some other clays, so is perfect for holding liquids and foodstuffs, once fired and glazed. Fired at a higher temperature than earthenware clay.
- Porcelain – usually white in colour and lends itself to bright white pottery pieces. Porcelain consists almost entirely of kaolin clay, can withstand high kiln temperatures which makes it durable, and as well as dinnerware, is used in decorative and more delicate pieces. The purer the kaolin, the whiter the porcelain.
- Polymer clay – not a natural clay in the sense of most of the others in this list, this is a modelling clay that requires baking, but it typically contains no clay minerals. Instead it is based on polymer polyvinyl chloride. Workable until cured, it doesn't require a kiln, but just the lower temperatures of an oven in order to harden.
- Air dry clay – the subject of this article, this modelling clay is usually made from or based on natural materials, but with a few things added so that it can be crafted with – usually including some natural fibres, such as paper, cotton, or wood. The branded clay that we have used, for example, has paper fibres in it which interlock to create an internal mesh, adding to its sturdiness. These additives give it a pliable texture that is easy to mould and shape with your hands. No kiln or oven required.

QUICK TIP:

If your clay feels too wet to mould, maybe because you have added too much water or slip, let it sit in the open air for half an hour so that some moisture evaporates. You should then find it easier to work with.

> **We won't be sealing this project as it's the porous** characteristic of the clay that we want to employ

QUICK TIP:

If you want to continue to work on a piece the next day, put it in a zip-lock bag (extracting as much air as possible) with a piece of slightly dampened paper towel to keep it fresh.

Below
Throw your keys or odds and ends in this dish for safekeeping, once sealed. Use any pre-made dish as a 'mould' for your own version – just remember to line it with something to avoid the clay sticking

Above
Dried pieces ready for a couple of coats of white paint. Once that's dried, you can decorate as you wish. Follow that with a gloss or varnish to seal to help resist knocks

Right (opposite page)
The kitchen table was a site of organised chaos while we were working, but that can't be avoided. This oak table has seen years of every family member making, gluing, and hammering...

PROJECT TWO: CLAY DISH

Next, we'll make a small dish, but this time we'll use the image transfer technique to decorate it. First, cover an appropriately sized dish with some cling film, dipping it in the centre, so you can sit the piece in to dry – the cling film will prevent the piece from sticking. Then print out a black and white image on your inkjet printer that will fit on your piece of clay, ensuring that you print the best quality possible, with as much ink as possible. (There are plenty of free images online to choose from). Ensure that, if you have text in your print, you reverse the image, or your transfer will be back to front on your project. Roll out your clay and use a small round dish as a guide to cut around. Remove excess clay, and very gently wet the top surface of the circle of clay. You hardly need any water as too much will cause the printed paper to stick to the clay – less is more.

Take your image and press the inked side down on the clay very lightly. Leave for a minute, and then check if the ink has transferred to the clay by lifting an edge. Leave for another minute or two if required, then carefully remove the paper. All being well, your image is now on the clay. As before, smooth the edge of the clay before sitting it in your dish. Leave to dry at room temperature and turn halfway through the drying process. If you notice any cracks or areas that need padding out a little, use your slip to fix them. Don't dry it in the sun, use heat tools, or leave it outside – it will crack!

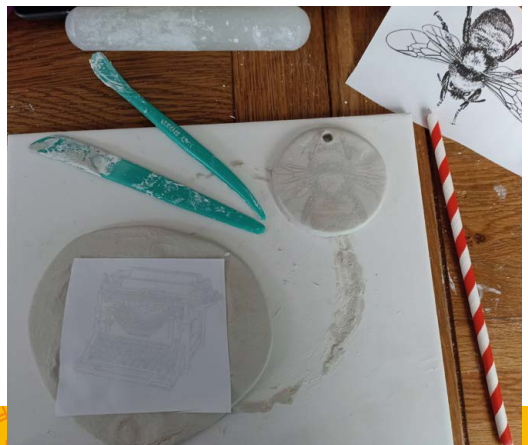
Once dry and sanded, you can paint it if you wish, emboss with some gilding wax, go over any lettering with a pen to make it stand out, or you can just seal it – which is what we chose to do, as a sealant will do wonders to protect your hard work. Leave to dry between layers of sealant/varnish, and then enjoy your make!

Above
If you dabble in other crafts, you may have what this author likes to call 'craft tool crossover' – tools you use for other crafts such as jewellery making, polymer clay work etc. will lend themselves nicely to air dry clay modelling. Cookie cutters are super-useful with clay, but don't use them for food prep afterwards!

Below
A selection of air dry clays, unopened and ready to use. Once you have opened a pack of clay, ensure that any unused clay is stored, tightly wrapped in its foil packaging, in an airtight container or zip-lock bag. Store in a cool, dark place and it will keep happily for up to a year

CRACKING CLAYWARE

If you want to take your clay journey further, there are many clever people undertaking inspiring air dry clay projects and sharing them online. We particularly like the idea of encompassing LEDs into clay designs – how about making a lantern and filling it with LEDs (**hsmag.cc/ClayLantern**)? Or, maybe a kit that contains all you need to make an air dry clay filament lamp (**hsmag.cc/ClayLamp**) is more appealing? Embrace the possibilities that air dry clay offers – make something useful but, more importantly, enjoy the sense of calm that comes with crafty clay manipulation.



SLIP SLIDING AWAY

Air dry clay starts to harden as soon it it's exposed to the air, so it's prudent to use some 'slip' to keep the clay soft and to prevent cracks from forming. So, what exactly is slip? Slip is a liquid mix of small pieces of clay in some water and it can be used as a form of glue to connect clay pieces together. It's your best friend when it comes to fashioning your air dry clay forms and figurines, and it's really useful to have some slip pre-made, on hand so that you can quickly turn to it when needed.

We found that mixing a ratio of approximately three parts clay to one part water worked very well to create a usable mixture, and the finished consistency resembled a very thick cream. It can be used for smoothing too, as well as 'gluing' parts together.

To make your slip, take a small amount of fresh air dry clay from the packet and pinch some small pieces as thinly as you can, making them almost paper-thin. Put two tablespoons of water in a container and add the small, thin pieces of air dry clay. Swirl the mix around until the water starts to turn milky in colour. Set aside for a few hours, or even overnight, and you'll find the clay and water have mixed nicely together, and the mix has a thicker texture. If the mixture doesn't feel thick enough, leave it a little longer with the lid off the container, e.g. an hour or so, and you'll find that the mixture starts to lose some of its moisture and thicken up. Give it a mix to get rid of any lumps, and it should then be ready to use in your projects. Practice will lead you to the right consistency, and you can make as much as you need before you start your clay projects. Just remember that you need to score both edges of your clay pieces using a sharp tool, if you are using the slip as a glue, and the pieces should then attach nicely together. When using slip to join two pieces together, take your time to really smooth the pieces together to prevent cracking.

Finally, make sure that you store your slip concoction in an airtight container, such as an old clean jam jar with its lid tightly secured, and you'll be able to use it for future projects as and when required.

TUTORIAL

Upcycle a Sonos Play:1

If you've got a broken or unused Sonos speaker sulking in the corner, it's possible to upcycle it for many different purposes using Raspberry Pi

MAKER

PJ Evans

PJ is a writer, software engineer, and tinkerer. His Play:1 now plays endless Rick Astley.

mastodon.social/@mrpjevans

Danger!
High voltage.

Many Sonos products have direct mains input which means residual charge can be present on the circuit board.

magpi.cc/dischargecap

Upcycling and the right to repair are hot topics right now. Just because an electronic device has failed, or is no longer required, it shouldn't mean instant landfill. When we came across a sad Sonos Play:1 that was more of a 'Silence:1', we decided to investigate the possibility of repurposing the high-quality speaker and enclosure. The result was a new lease of life with plenty of options within its capabilities. This tutorial shows how to do it and is not just for a Play:1, but more of an example of how you can give dead tech a new purpose.

01 Build your stack

Let's start with Raspberry Pi itself. We selected a 3A for this project thanks to its smaller form factor which means it doesn't get in the way of the main speaker in the unit. You could also use a Raspberry Pi Zero 2. There are many choices for audio output, but the one thing you need is amplification. Most DAC HATs are line-out only, relying on external amplification, so make sure yours can be wired directly to speakers. The Sonos Play:1 speaker is 4Ω, so we selected a matching amp: in this case, the Justboom DAC and AMP combo. Assemble everything according to instructions and, from now on, use the 20V power supply connected to the HAT to power everything.

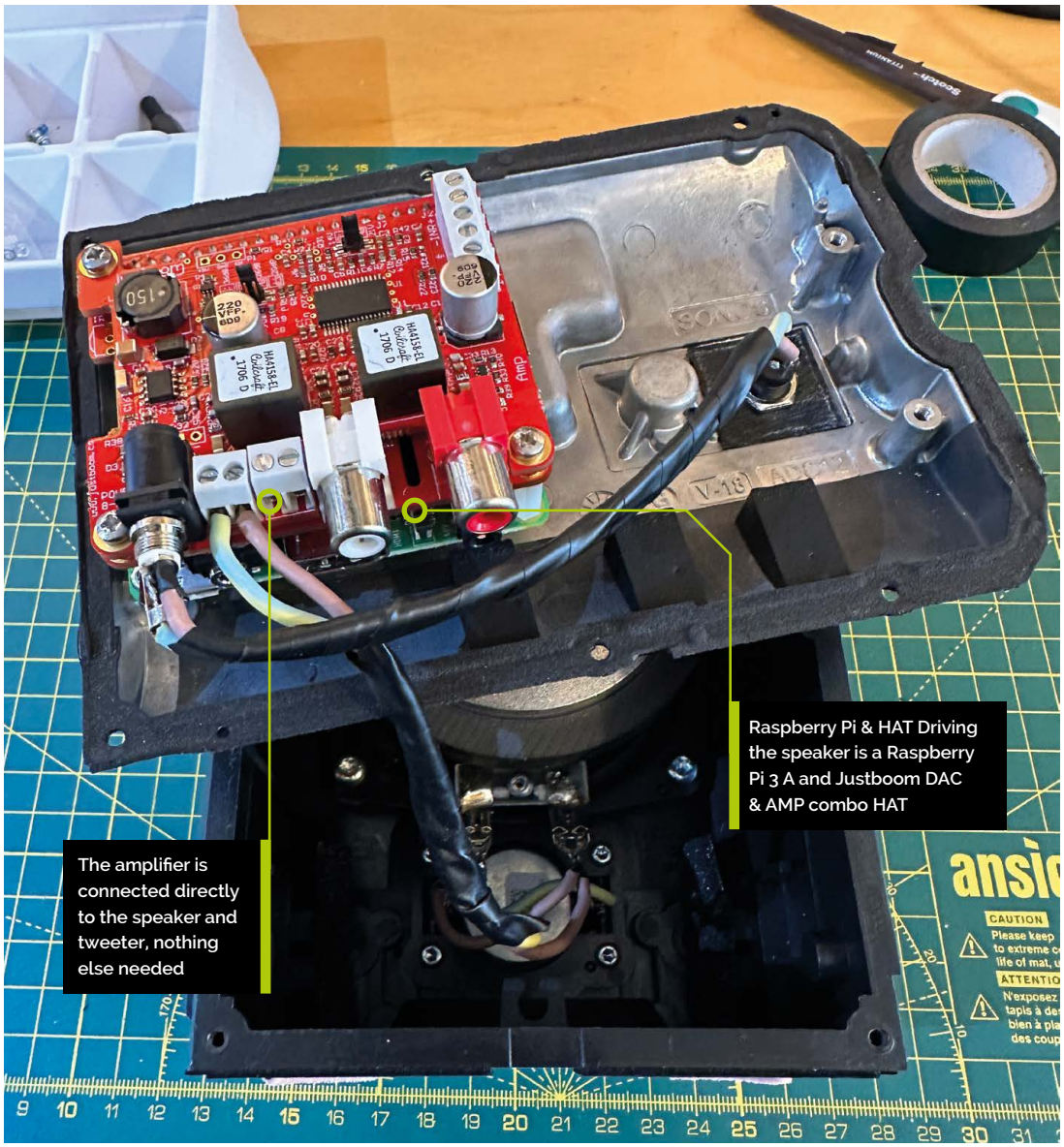
02 Prepare the operating system

As is traditional in these tutorials, it's operating system time. Depending on your plans, it's your choice whether you have a desktop or not (VNC into a speaker? Why not?) but we went for Raspberry Pi OS Lite (64 bit) and wrote the image to an SD card using Raspberry Pi Imager, making sure Wi-Fi and SSH access were configured in advance as, once in the enclosure, we won't have keyboard or video access. Once installed, make sure you can get SSH access over your network then run `sudo apt update -y & sudo apt upgrade -y` so that everything is up to date.

▲ The original Sonos Play:1. A powerful speaker assembly in a small good-looking unit. Lucky for us there's a lot of space inside!

03 Disassemble your Sonos Play:1

Let's create some space for the Raspberry Pi and the amp. Carefully remove the rubber strip on the base that hides the screws. Now remove the Torx screws. Lift out the base then slide the speaker



You'll Need

- Sonos Play:1 (or similar)
- Amp HAT (**magpi.cc/amp4**)
- 20V (at least 12V) power supply with barrel connector (**magpi.cc/20v4a**)
- Approx 1m speaker-grade wiring
- 20V wiring (optional)
- Size 5 and 6 Torx screwdrivers
- Rotary tool and 3mm bit

grille off. Remove the tape from each corner to reveal the screws holding the top section and remove them. Pop off the top section and detach the ribbon cable from the mainboard. Now remove the remaining screws to carefully separate the front section from the back. For a complete guide, see this iFixIt article (**magpi.cc/play1mb**).

04 Remove the mainboard

IMPORTANT: This part involves potentially harmful electricity. Minors must be supervised. Take a look at the mainboard on the rear part of the enclosure. See the three brown capacitors? They are likely to be holding charge from the mains electricity. Do not touch them, especially the contacts to the motherboard. Carefully remove the wiring loom to the speakers then unscrew the board. Remove the board by the edges. Ideally, at this point you should discharge the capacitors for safety. See the guide in the warning box. Either way, discard the mainboard at this point unless you intend to recycle it.

05 Clear out the wiring

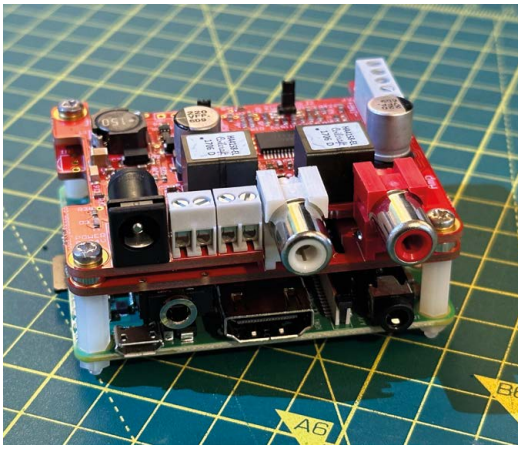
At this point you should have a plain metal backplate to the whole enclosure. This is where the Raspberry Pi and amplifier will be installed. Turning our attention to the main section, you'll see some wiring still installed. We need to remove all of this. Start by looking at the

Top Tip

Ice cube trays are your friend

There are a lot of bits you need to keep track of during disassembly. Consider using an ice cube tray to keep things separate and in order of use.

TUTORIAL



The Justboom DAC & AMP is a DAC HAT with an amplifier that 'piggybacks' on top to create a single device

Here you can see the original PCB for the Sonos system. The large brown capacitors may be carrying high voltage charges and should not be touched

speaker terminals. The wiring loom is connected using spades, and we can reuse those, so using needle-nose pliers, remove the terminals. Make sure you note which are positive and negative; they are different sizes and we want to make sure we reattach using the same polarity. Finally, clip out the smaller wires near the base which are no longer required.

06 Build the new wiring

Time to heat up the soldering iron. Clip off the spades from the original wiring (which can now be discarded). Make sure the speaker wire you have chosen is a suitable size to fit in the screw terminals of the amplifier. Now, matching the original polarity, take a decent length of speaker wire (you can trim it later) and solder to the main speaker spades, then using a 10cm additional strip, solder the tweeter spades to the main spades so they are in parallel. Silver the opposite end of the wire and screw into the + and – terminals of the amplifier for the left channel. Once connected, return the spades to their original terminals.

07 Configure the DAC

Let's return to the Raspberry Pi. With the speakers connected, boot up and get a command line prompt either directly or via SSH. At this point the DAC & amp are unknown to the operating system, so we need to make some changes. Instructions vary for different DACs. For Justboom, we need to edit config.txt to load the drivers at boot time. Run this command:

```
sudo nano /boot/config.txt
```

Find the line `dtparam=audio=on` and comment it out and add the lines below so it matches:

```
#dtparam=audio=on
dtparam=audio=off
dtoverlay=justboom-digi
```

CTRL+X to save, then **Y** to exit. Reboot now with `sudo reboot`.

08 Test time!

Let's make some noise! White noise to be exact. Get back to a command prompt and first let's check the volume levels. Enter `alsamixer` and you'll see some controls. Use the **arrow keys** to move along to 'Digital' and turn it up to about 50%. If you see 'MM' there, press **M** to unmute the channel. Press **ESC** to leave. Now run this command:

```
speaker-test -c 1
```

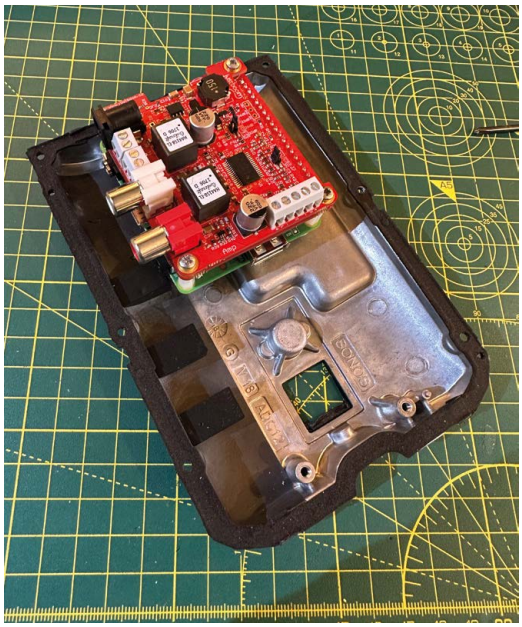
If all is well, you'll hear a static-like sound from the speakers. Lightly press your fingertip against each speaker to feel the vibration. When you're happy both are working, use **CTRL+C** to stop playback.

Top Tip

Not just Sonos

This project isn't just for a Sonos Play:1. How about rescuing an old vintage radio or hi-fi unit?

▼ The back of the unit with the Raspberry Pi stack installed. All that's left is to wire it to the speakers



09 Mounting the Raspberry Pi

Examining the Sonos Play:1 backplate we encounter a bit of luck. The top two screw terminals are exactly the same width apart as the standard Raspberry Pi mounting holes. Hurrah! It's not all plain sailing though. They are M.3 size and the Raspberry Pi holes are M2.5. So if you're feeling brave, use a low-speed rotary tool with a 3mm bit to carefully bore out the two holes to M.3 size. Note: You can permanently damage your Raspberry Pi at this point, take your time. Now, using the screws from the original board, you can mount the stack to the backplate. It's a good idea to line the surface with insulation tape to avoid short circuits.

10 Power wiring

We've been using the 20V power supply as the standard Raspberry Pi 5V supply isn't enough to drive the amplifier as well. Now the original mainboard has been removed, there is a space previously occupied by the Ethernet connector that can be used to feed the power through to the board. If you're feeling fancy and have the kit, consider 3D printing a cover for the aperture that can hold a chassis-mount barrel socket (files here: **magpi.cc/play1socket**). Then you can create a link between the socket and another connector internally. Now the power supply is no longer tethered to the Sonos Play:1.

11 Reassemble

Before getting the screwdriver back out, make sure everything is still working as expected and there's no chance of any short circuits when the unit is put back together. If you have too much slack on the speaker lead, now is the time to trim it down and re-silver. You should have enough that you can easily open up the two halves of the enclosure should you need to. Now reverse the earlier process. Reattach the backplate to the main body, add on the top piece, slide on the speaker grille and then the base and its rubber strip.

12 Final test

Once everything is back together, it's time for a final test run. Power up the upcycled unit, and make sure you can get a Wi-Fi connection (despite the thick casing, we've found the Wi-Fi to remain reliable – of course, there's nothing to stop you using a wired connection if you prefer). Run the speaker test again, altering the volume if you need to. You may have noticed a potential problem. We've only got one speaker connected to the left channel? Don't we have stereo in 2024? Well, yes, and we need to mix the two channels and also find a cool application for our new audio toy. That's for next month.

◀ When testing, use alsamixer to control volume

TUTORIAL

Build a hardwood case for a Raspberry Pi 5

Generate a load of rare exotic dust, and build a home for your Raspberry Pi 5 at the same time

Andrew Gregory

Everything in Andrew's garage is covered in a thin film of orange dust from working with wood.

Right
A bespoke home for our little desktop computer

As part of a separate project, we acquired a 12 × 70 × 1200 mm length of meranti wood. Meranti (aka Philippine mahogany) is a hard, resinous wood that's ideal for outdoor uses such as decking, and building those snazzy boats that zip up and down the Grand Canal in Venice. Naturally, we used ours to build a case for a Raspberry Pi 5.

I use my Raspberry Pi 5 as a desktop machine – any time I need to access GPIO pins, those pins are on a Raspberry Pi Pico – and so there was no need to add a hole in the lid of the case. Rather than add hinges, I thought I'd try my hand at a sliding lid, so I'd need to carve a couple of grooves into the inside walls of the case to allow another piece of wood to move freely along them. And at the back of the Raspberry Pi 5, where the Ethernet and USB cables

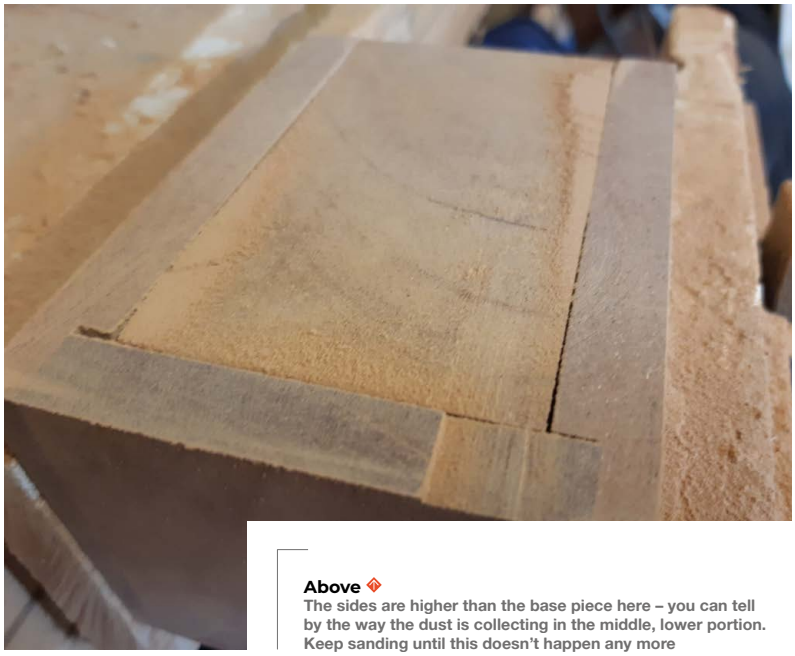
go in, I'll just leave that bit open, with the option of enclosing it partially further down the line.

Visually, I'm aiming for something that looks a little bit 1960s. I thought about using dovetails for about ten seconds before I realised what a time sink that would be, in the end opting to use rabbet joints for the longest sections where two pieces of wood meet – that is, I'll cut out a lip along the length of piece A, and piece B will sit within that lip, so that the two pieces of wood are touching on two surfaces rather than just one (I'll also use a router, rather than a hammer and chisel). This has a couple of advantages over a straight butt joint. You could argue that as it increases the contact area compared to a butt joint, it will enable us to apply more glue. That may be true, but the effect is going to be negligible, especially with a purely decorative item. The real reason is that I want to keep each piece of wood the same width, and using a rabbet joint like this is a way of bringing the sides in slightly without having to alter the overall width of the piece I've chosen to use as a base. The wood that I'm using has been thicknessed and planed with right angles on all sides by a huge piece of machinery built in the 1940s, when everything was made of cast iron and weighed a ton. As soon as I start messing with it, I'm going to throw it out of true, so I'd rather not.

To carve these rabbets I'll use the rabbet router bit. This is a circular bit with two straight sharp edges, and it comes with a selection of differently sized interchangeable bearings. With a larger diameter bearing, the cutting edges can't go as far into the wood; with the smaller bearings, the bit is free to cut further. It's an intuitive, low-tech tool, but there's no way to calibrate it. For that, we used a scrap of spare meranti the same thickness as the stuff we're using, and made experimental cuts with different-sized bits until we found one that cuts 12 mm deep. With the router bit protruding roughly 6 mm from the base of the router (again, this is a cheap router from the middle aisle of a German supermarket, so there's no way to measure this other than by making a cut and measuring that), we found a combination that makes a decent right angle for one piece of wood to settle →

Above
This router bit can only cut as deep as the bearing attached underneath allows it to, so you can cut rabbets to a consistent depth

Above Left
The two sides of our case, with rabbets cut to fit the base and back end



Above
The sides are higher than the base piece here – you can tell by the way the dust is collecting in the middle, lower portion. Keep sanding until this doesn't happen any more

Above
The first bit of Danish Oil reveals the grain of the wood under all that dust

QUICK TIP:

Rather than faff about changing router bits, it can be tempting to put one in an electric drill, especially if you only need to use it on a small area. Don't do this – you'll ruin your workpiece. Ask us how we know.

into another. I carved a cut into the two side pieces of wood, which I had already cut to the length of a Raspberry Pi 5, plus a couple of centimetres.

Into those same side pieces I used a smaller rabbet bit to carve a notch along which my lid would slide; I then had to make another rabbet cut approximately 2 mm deep so that the lid would fit comfortably in that notch.

With the joints cut, I located where I wanted the holes in the case to be, drilled pilot holes, then enlarged and lengthened those holes using the router with a cove bit – this is a semi-circular bit with two sharp edges, that works when you want to carve concave edges. Now it's time to glue the pieces together. We liberally applied Titebond wood glue (remembering not to glue the lid shut), clamped it up, then left it overnight.

I realised embarrassingly late on that I couldn't just drill a hole in the side of a box 12 mm thick in the shape of the sockets on the Raspberry Pi. Instead, the holes for the cables need to be big enough to fit the cable, complete with the plastic bits that you hold when you plug the cables in. I decided that I'd have to widen the holes, and in widening them, they'd overlap. So rather than having separate holes for the USB-C and HDMI ports, I'd have a slot that would allow all three ports access to the outside world.

Similarly, the power button is tiny. My smallest drill bit is 3 mm in diameter, which would be big enough to poke a pin through to press the power button, but I decided that the hole would have to be big enough to poke a little finger into to turn the Raspberry Pi on and off.

At this stage what we've got is extremely rough. It looks wonky, the joints look a bit gappy, and no single piece of wood is the same length as the other. This is where the magic happens: the magic of sandpaper. If woodworking has taught us anything, it's that patience is a virtue. If you rush it, you'll make mistakes; if you're stuck, the best thing you can do is go off and have a cup of tea and let your subconscious mind work on the problem while you

Above
Anticlockwise from top-right: 80 grit, 240 grit, and 400 grit sandpaper. Go up through the grits to get a smooth, even finish

Above
We located the holes from the inside of the case by eye – this looks about right to us

do other things. Nowhere is patience more important than when you're sanding.

We're going to use very coarse sandpaper (80 grit) to remove the inconsistencies from the case. Where the sides meet the base, for example, there's an approximately 1 mm height difference, which we're going to remove. If we had better, sharper tools, there's a chance that we could do this with a plane, as it would be quicker and produce nice aesthetically pleasing wood shavings. Instead, we'll use a piece of double-sided sticky tape to attach some 80 grit sandpaper to a flat, square piece of wood that we'll use as a sanding block – that way we know that we're not going to remove wood unevenly.

This stage takes a long time, so strap in. Every time you finish a side, give it a dust off, and if the sandpaper gets clogged, change it for a fresh piece. Eventually you'll reach a state where there are no pockets for dust to collect in, and you shouldn't be able to feel any ridges where two pieces meet.

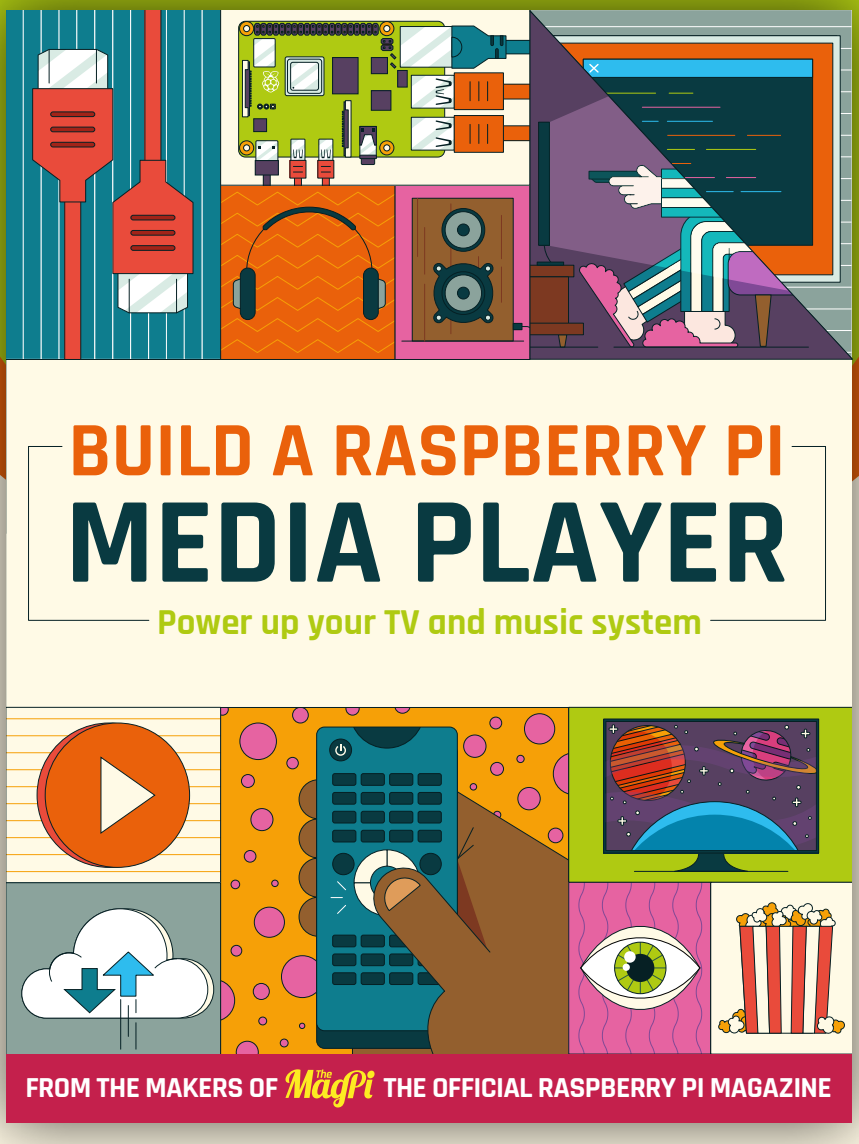
With our surfaces sanded flat, we can add a small flourish with the router and our round-over bit, which adds a rounded corner to the previous sharp edges. Now, we sand the case again, and again, and again, using a series of different pieces of sandpaper of decreasing roughness – a process that you'll see proper woodworkers call 'moving up through the grits'. We started with 80 grit paper, then sanded again with 240 grit, then 400 grit, then 600 grit, and finally 1200 grit, this time not to remove large amounts of wood, but to achieve a fine smooth finish. Each grit removes the scratches that were introduced by the grit before, so higher grits equals a smoother surface.

What we have now is a smooth, dusty box. Depending on what wood you use, it may look muddy, or even grey. To reveal the grain of the wood, and add a waterproof layer that will harden as it dries and make it look really lovely, we give it a wipe with cloth and some Danish Oil. Now our Raspberry Pi 5 has a worthy home! ◻

QUICK TIP:

It feels counter-intuitive, but in this build we added the small detail before we glued the big pieces together. That's because, if you ruin one piece of wood, you've ruined one piece of wood; if you ruin a piece of wood that's glued to three other pieces of wood, you've ruined four pieces of wood. Learn from our mistakes!

Your FREE guide to making a smart TV



magpi.cc/mediaplayer

PCTG

Move over PETG, there's a new glycol-modified terephthalate in town

Ben Everard

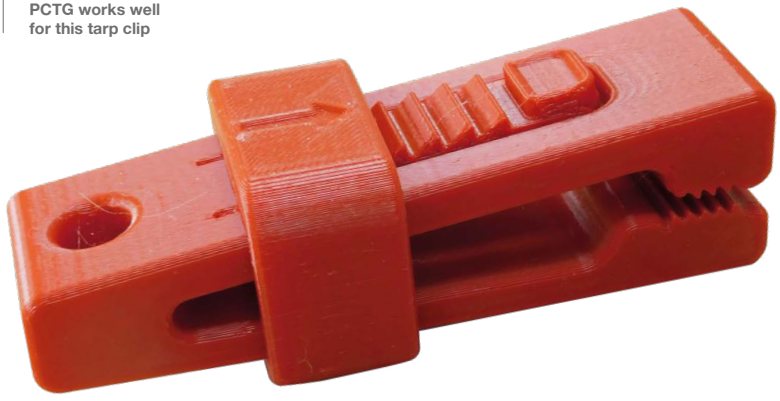
Ben's house is slowly being taken over by 3D printers. He plans to solve this by printing an extension, once he gets enough printers.

If there was a prize for the most intimidating sounding 3D printer filament, poly cyclohexylenedimethylene terephthalate glycol-modified would probably win it, but in use, PCTG as it's more commonly known, is a straightforward plastic to print with.

We printed the filament at 265°C with the bed at 90°C. While we do print inside an enclosure, it's not heated. We just slightly modified a PETG slicer profile and it worked. This should be within the range of most home 3D printers.

Chemically, as well as symbolically, PCTG is very similar to PETG, and shares many of the more famous filament's properties, including durability and resistance to temperature and chemicals.

Below
Excellent layer adhesion and toughness means PCTG works well for this tarp clip



There are two big ways where PCTG shines in comparison to PETG: it's got a higher impact resistance, and it's got better layer adhesion. The marketing material tells us that it's glossier and more transparent, but honestly, we couldn't tell the difference. The YouTube channel CNC Kitchen has an excellent test on the mechanical properties at: **hsmag.cc/CNCKitchenPCTG**.

The downsides of PCTG compared with PETG are that it's available in fewer colours, and it's a bit harder to find. Historically, it has been more expensive, but the gap has closed significantly in recent years.

We tested this filament out with a range of different projects around this month's cover feature. It proved particularly good for tent pegs which can take a whack. On the other hand, the carabiners faired far better in PLA – despite the strength of PCTG, it's not as stiff as PLA, and that caused the carabiner to deform. In fact, PCTG isn't even as stiff as PETG, which isn't the stiffest plastic to begin with. This slight flexibility is part of the reason it can withstand larger impacts. Carbon fibre-reinforced PCTG is available for cases when you want PCTG's properties, but need it to be stiffer.

If you're not planning a trip to the great outdoors, there are still plenty of cases for PCTG. Most of the time this is going to come down to durability. The higher layer adhesion could also be great for objects that have to have some stress across the Z axis. It's not perfect, so this is still weaker than the X and Y axis, but it's better than most other easy-to-

print filaments. Potentially, this could save you from having to split an object up into multiple parts to print, and that could mean saving time and filament.

Perhaps the most significant downside – when compared to PETG – for us, is the lack of recycled options for PCTG. While recycling plastic is still an area fraught with misinformation, and doesn't always have the environmental impact we hope it could have, on the whole, recycled plastic is a significant ecological improvement over virgin plastic, especially oil-derived plastics like PETG and PCTG.

PCTG really deserves to be a more popular filament. We found it printed really well, and the combination of high-impact strength and high layer adhesion is a great combination for many mechanical parts.

Above
Despite advertised claims, we've been unable to persuade PHB filament to compost

Right
The flexibility of PCTG makes it a poor choice for some applications, like this carabiner

PHA UPDATE

Back in issue 60 we tested out PHA filament which promised to be a truly compostable 3D-printable filament. Unlike PLA, which requires very specific conditions to break down – so specific that in reality it's not possible for most people to compost – PHA, it is claimed, will break down in normal home compost.

We placed a test print in a home wormery for over 18 months, and there's no noticeable degradation. While there may be conditions that it will break down in home compost, it's clearly not as simple as just putting it in with the rest of your compost and waiting.

Our wait for a truly compostable filament continues.

TUTORIAL

Bring a 1960s spy camera back to life with 3D printing

Get pictures from a Minox microcamera by using 3D-printed technologies

Rob Miles

Rob has been playing with hardware and software since almost before there was hardware and software. You can find out more about his so-called life at **robmiles.com**.

Extend your photography and 3D printing skills by getting a classic camera back into action.

Minox 'spy' cameras are popular amongst camera collectors and those looking for a quirky way to take photographs – this despite their production having ended many years ago. The cameras are very well-made, and it is not hard to find working examples at reasonable prices. There are people who can provide you with film cassettes and develop them for you, but you can also 3D-print tools that let you produce your own pictures with this marvellous machine. In this article, we are going to look at the camera itself and find out what makes it so special. Then, we are going to work through the photographic process – from creating your own 9mm wide film to scanning your pictures into a computer – and we'll discover how we can use 3D-printed components at every stage. There are full details of all the references in the repository for this article which can be found here: **hsmag.cc/MinoxResources**.

Figure 1 (opposite) shows a Minox B camera along with a film cassette and a pair of glasses, to show the size of the camera. If you were found carrying a Minox 60 years ago, it would be assumed that you were a spy, because you probably were. If you were seen wearing those glasses, they might well decide you were a spy too. Minox cameras were used extensively by both sides in the Cold War. The camera can produce extremely detailed pictures, and is easy to use and conceal. James Bond used a Minox camera in the 1969 film *On Her Majesty's Secret Service*, although he notoriously held it upside down – probably because this looked cooler. Even the chain fitted to the camera comes equipped for spying. The beads on it correspond to focus distances which you can set on the lens. This makes it easy to take super-sharp pictures of things (for example, secret documents) just by holding the bead on the subject and pulling the chain tight to set the distance.

The Minox B camera is entirely mechanical, although it contains an electric light meter powered

Figure 1
The camera has been extended to its 'open' position to expose the lens. When the camera is closed, the film will be wound on to the next frame

by a selenium light detector you can see on the right-hand side of the camera in **Figure 1**. There is a tiny needle in the light meter window above the detector. You adjust the right-hand shutter speed dial until the arrow matches up with the needle and your exposure is set. The left-hand dial sets the focus distance. You can set the focus so that everything further than 8ft away will be sharp. If the light is too bright, the camera has built-in filters you can slide in front of the lens to darken the image. If you want a Minox camera of your own, they can be picked up for around the price of a good-quality video game. →

> **There is a tiny needle in the light meter window** above the detector

YOU'LL NEED

- **Minox microcamera that uses Minox microcassettes**
  Search your favourite auction site for 'Minox B'
- **3D printer**
  (preferably one that can take a 0.2mm nozzle)
- **Some black 3D printing filament**
- **Some 35mm black and white film, and empty 35mm film cassettes**
- **A film changing bag**
  (where you can load and unload the cassettes)
- **A developer tank and a film spiral**
- **Access to a film scanner**

Figure 2
The Minox camera has been used to take super-secret pictures of Hull's The Deep aquarium and the Hull tidal barrier…

AUCTION TIPS

The author has bought many items (including Minox cameras) from 'the world's favourite online auction site', and considers himself familiar with the ways of buying and selling things (mainly cameras). He therefore presents these handy tips for anyone thinking of venturing online to get some gear.

1. Buy things for fun, not profit. It is hard work to buy cameras and make money from them. Much better to think of it as a hobby you are spending a bit of cash on. Many years ago, the author used to spend quite a lot of time and money on video games. These days, he is more likely to spend the price of a video game on an old camera and then have a bit of fun trying to make it work. If things end badly, he puts the camera back on sale with a humorous description of the problem, and usually gets some of his money back.
2. Don't get carried away when you are bidding. You will receive messages such as 'Don't let it get away' or 'It could still be yours' when you make a bid. Ignore them. Get a feel for the 'right' price and don't go beyond this. Unless you are bidding for the one and only Holy Grail (which is unlikely), there will always be another one coming along.
3. Beware of silly priced items. Listing an item for sale costs very little. Some sellers create listings with prices way above the market rate to try and drive up the market. You can use the 'show only completed sales' filter to see how much items are really selling for.
4. 'Untested' usually means broken. If you buy an item described as untested, you are betting that you are smart enough to test (and then perhaps mend) what you are going to get. The author has lost this bet many times.
5. 'Tested' can also mean broken. Some sellers regard 'camera clicks when button pressed' as a passed test. Read the item description very carefully. Sometimes a 'tested' camera will have a broken exposure meter or film rewind. Some cameras are sold as 'film tested' (with samples), which is the best kind of tested.
6. Look for established sellers. The author has met some lovely folks buying and selling stuff. Look for people with good feedback who have been around a while. And don't be afraid to ask questions about what is being sold. A genuine seller will be happy to help.
7. Shop prices can be cheaper than auction prices. For a long time, the author thought that buying via auction was the cheapest way to get something. This is not always the case. Specialist dealers can be competitive and may offer returns and warranties. Check out their stores as well as auctions.

Figure 3
The biggest problem with small negatives is keeping dust off them

THE SMALL PICTURE

The Minox camera produces tiny images on photographic film which is just 9 mm wide. **Figure 2** shows this size in comparison to 110 cartridge film (16 mm wide) and 35 mm film (35 mm wide). You could fit many Minox images onto a single 35 mm picture. This does limit the amount of detail that you can get, but the pictures are very usable, and it makes film much cheaper.

Figure 3 shows a print from one of the Minox negatives shown in **Figure 2**. The detail on the image is impressive and would be much improved if film with smaller 'grain' had been used. A photograph is made of tiny particles of silver which are created in the parts of the film that have been exposed to light. These particles are the 'grains' that make the image. The faster the film (i.e. the more sensitive to light it is), the larger the grain particles, and the lower the quality. The grain in **Figure 3** is quite noticeable. Using a lower-speed film would have produced a more detailed picture.

You can take colour pictures too (although processing these at home is more difficult). If you want to have your films processed (and your cassettes refilled), search for 'Minox film processing' online. However, the author much prefers to do everything himself. Let's find out how to do it.

Figure 4
You can also get a slicing block that will cut a 16mm wide film strip to be used in other miniature cameras

A SLICE OF LIFE

The first problem that you encounter when you want to use your Minox camera is that 9mm wide film is no longer made. Fortunately, this problem is easy to solve. **Figure 4** shows a film slicer which can be used to cut 35mm film into 9mm wide strips. Film is wound from the cassette on the left to one on the right. On the way, it is split by three blades embedded in the block in the middle. You place a new cassette in the left-hand slot, pull out a length of film, and attach it to the spool inside an empty cassette you place in the right-hand slot. Then you put on the light-tight cover (this step is important) and turn the handle to pull the film from one cassette to another. When you have finished, you have a cassette full of sliced film. You can create your own film slicer from 3D-printable designs (**hsmag.cc/FilmCutter**), or you can buy a ready-made one (**hsmag.cc/MinoxCutter**).

Figure 5 shows the result of the slicing operation. The receiving cassette holds two lengths of 9mm wide film. Now we have the sliced film, the next challenge is to get the film into the Minox cassette. This must be performed in complete darkness. The easiest way to do this is to use a film changing bag. This is a light-tight bag with elasticated cuffs, allowing you to put your hands inside it without letting light in. The bag has a zip at one end which you open to put in the 35mm cassette containing the sliced film and the empty Minox cassette. Then you close the zip, put your hands inside the bag, pull out a length of sliced film from the 35mm cassette and roll it up tightly. Next, you put the rolled-up film into the feed chamber of the Minox cassette and put the lid on the feed chamber.

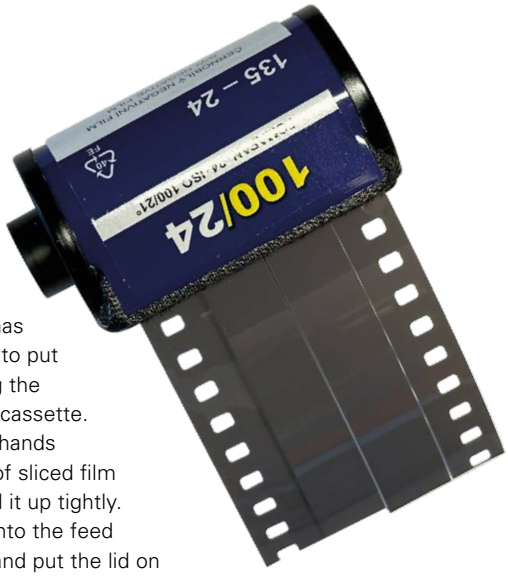


Figure 5
The author has been unable to think of a use for the strips of sprocket holes that are also created by the slicing process. Although, he did once load some into a Minox cassette by mistake

Figure 6 shows a cassette with an unexposed film in the right-hand chamber. The film to be exposed is pulled out of the cassette onto the take-up spool in the left-hand chamber. The final task is to stick the film to the take-up spool, put the spool inside the cassette, and then put the lid on the cassette. These steps can be performed in the light. We can then tape the lids to hold them in place (the best kind of tape to use is 6mm wide Tamiya Masking Tape, which is normally used when painting models). Now we have a cassette that we can load into the camera and use to take some pictures. →

Figure 6
The right-hand chamber in the cassette holds unexposed film. The film is wound onto the spool in the left-hand chamber after each shot

MINOX HISTORY

The Minox camera was designed in the 1930s by a German engineer with the wonderful name of Walter Zapp. It was one of the earliest 'system' cameras. Along with the camera, you could get a special tripod to stand it on, an adapter for binoculars, a film developing tank, and even a briefcase-sized enlarger you could use to create prints of your images. In the 1970s, the Minox B was replaced with the Minox C, which added automatic exposure and was even smaller (although the lens was fixed focus, which reduced the image quality slightly). However, by the end of the 20th century, digital cameras were becoming cheaper and able to compete on quality, leading to Minox camera production ending in 1996. The Minox name lives on, but these days, it is more likely to be attached to a pair of binoculars.

QUICK TIP

When printing delicate items like Minox cassettes, it is a good idea to reduce the print speed to about a quarter of your usual speed.

Figure 7
The Minox tank is on the right-hand side

Figure 8
Make sure to get rid of all the dust on the film and the holder before scanning, just like the author didn't

QUICK TIP

Before you try to load a cassette in the dark bag, it is best to practise a few times in the light.

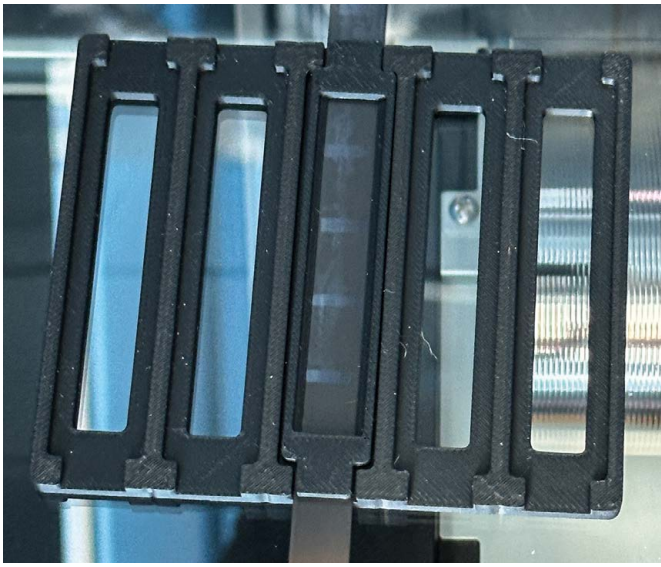
INTO THE SPIRAL

To develop your own photographs, you need a developing tank. This is a light-tight container which holds the film and the liquids that develop the image on the film and then fix the film so it can be viewed in the light. The Paterson brand is popular, and its tanks have been available for many years. Search for 'Paterson Universal' tank. The tank is supplied with a 'spiral'. You push your film into the spiral and then load it into the tank. To process Minox films, you need a spiral which can take the 9mm wide film. You can find a design for one at **hsmag.cc/PatersonFit**. You put the exposed film and the developing tank into your light-tight bag and pull the film out of the cassette and push it into the spiral. Then, you put the spiral on the holder, pop it into the tank, and put on the tank lid. Now you can take the tank out of the light-tight bag and perform the rest of the development in normal light.

Figure 7 shows a Paterson tank, and a spiral partly loaded with Minox film on the holder on the left. If you wanted to develop multiple films at the same time, you could print several spirals and load them all onto the spindle. Just make sure that you use enough developer to cover all the spirals. If you can afford it, you can get another wonderful piece of design from Walter Zapp in the form of the Minox daylight developing tank shown on the right of **Figure 7**. This lets you develop Minox cassettes without needing a darkroom. The Minox cartridge is placed in the light-tight compartment on the right-hand side of the Minox tank. You then rotate the cylinder sticking out of the top of the tank to pull the film out of the cartridge, and wind round the outside of the cylinder in the tank for development. Once the film has been developed, it needs to be dried in a dust-free environment (the author uses the bathroom) and the next step is to scan the pictures into a computer.

SCAN THE HORIZON

Now that we have our images, we must scan them into a computer. We need a flatbed scanner which has a backlight for scanning negatives. You can pick up such scanners quite cheaply, but make sure that you get the software drivers for them as well. In Hull, UK, where the author lives, there is a local 'library of stuff' (**libraryofstuff.co.uk**) where you can rent things like film scanners (and lots of other things) for very low prices. You might find one in your area. You might also like to investigate local photography clubs where they might have a communal scanner, or someone happy to help you further your hobby and scan some negatives for you.



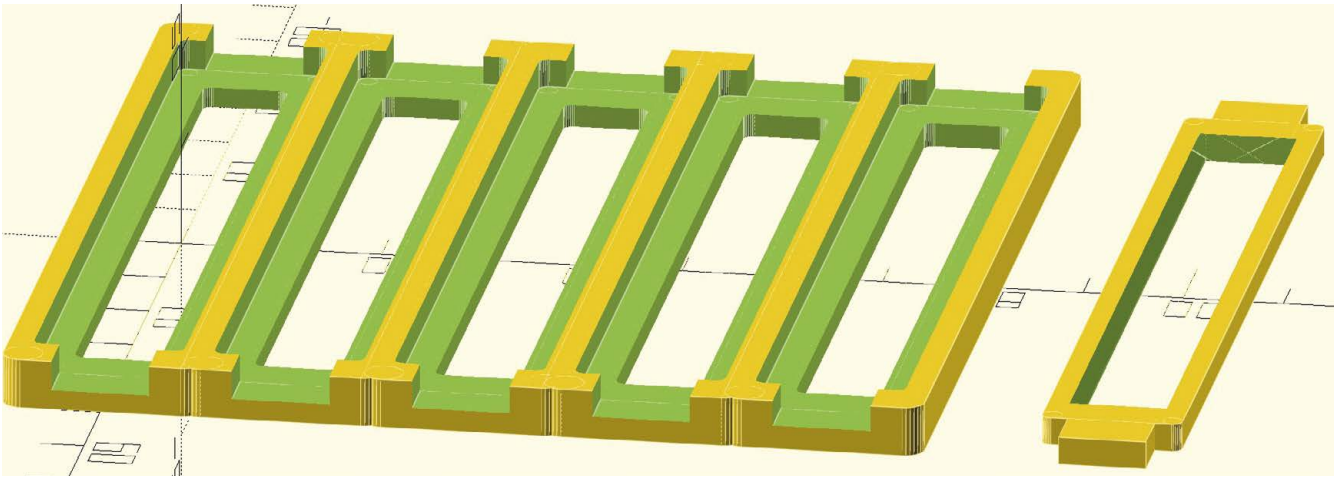
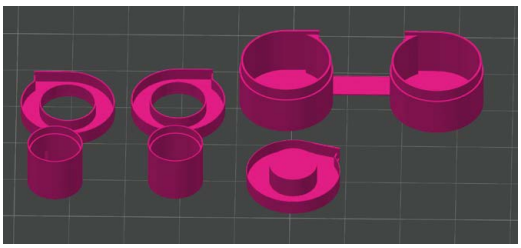


Figure 8 shows the film in a film holder, ready for scanning. Scanners are usually provided with negative holders, but you won't find any that fit Minox film. This is another problem we can solve with our trusty 3D printer.

Figure 9 shows a film scanner design produced by the author which is easy to print and use. Each of the holders is a slightly different height so that we can compare different film positions and then print a set of holders with the best possible focus. There are sets of holders available in the resources for this article.

I SPY WITH MY LITTLE MINOX

The author has had a lot of fun with his 'spy' camera. The complexity of producing film and creating pictures adds a lot to the photographic experience. You really feel like you own the shots that you end up with. The camera itself is a genuine marvel of design and construction. It doesn't look like something made over half a century ago. And, once you have had the experience of handling film in a light-tight bag and processing, you can work with other sizes and types of film. A tiny camera, like a Minox, can be the first step into a rewarding photographic hobby. And making it work makes very good use of other maker skills.



> **The complexity of producing film and creating pictures** adds a lot to the photographic experience

WHERE DO WE GET MINOX CASSETTES?

Minox cassettes were last sold in the 1990s, nearly 30 years ago. Fortunately, there are still quite a few around, and you can find 'new old stock' Minox films. The cassettes can be reused, and you can even obtain metal versions, at a price. Search for 'Minox cassettes'. However, what we really want to do is 3D-print our own cassettes. There are some designs online, but these don't fit the author's camera. He has made a remix of a design with improved take-up spools. He is also working on a cassette which has a take-up spool on each end, to ease loading. Rather than having to wind the film into a small roll by hand, you will be able to just wind it directly into the cassette.

The cassettes can be printed on a normal 3D printer, but they require the use of a 0.2 mm printer nozzle (the standard printer nozzle size is 0.4 mm) because the walls of the cassette lids are very thin. The author is working on a cassette design which can be printed with a 0.4 mm nozzle. It won't be able to hold as many shots, but it will be easier to make. You will also need to add felt light traps to the slots in the cassettes – search for 'self-adhesive felt' and get some which are 0.5 mm thick. You can find all of the designs in the GitHub repository for this article here: **hsmag.cc/MinoxResources**.

QUICK TIP

The blades in the slicer are very sharp. Be careful to keep your fingers away from them when you are slicing film.

Figure 9
The design was produced using OpenSCAD. The code is in the repository for this project

Left
You should use black filament to make your cassettes, not the colour shown here

TUTORIAL

Make a retro telephone which answers your questions

Add voice input to a Raspberry Pi-powered telephone and create a large language model telephone exchange for the phone to talk to

Rob Miles

Rob Miles has been playing with hardware and software since almost before there was hardware and software. You can find out more about his so-called life at **robmiles.com**.

Figure 1 (opposite page) The Exchange contains an 8GB Raspberry Pi 5 with a 256GB SSD. The telephone contains a Raspberry Pi Zero

Build on the Raspberry Pi-powered telephone created in HackSpace magazine issue 73 to add voice input. Then create a Raspberry Pi 5-powered large language model (LLM) telephone exchange for the phone to talk to.

Figure 1 shows the author's 'Red Telephone'. To the left of the phone is 'The Exchange', a device which uses an LLM to answer questions. The user can pick up the phone, dial a number, ask a question, and put the phone down. After a while, The Exchange will call back with an answer which may not be correct, or even rational, but is always interesting. You can find all the construction details for the phone and The Exchange in the GitHub repository for this project at **hsmag.cc/Pi_Phone**.

CARBONATED AUDIO

Figure 2 shows the microphone in the telephone handset. The microphone is packed with carbon particles which vibrate when hit by sound waves. The vibration causes the electrical resistance of the microphone to change and was used to produce a signal to be sent over the phone lines. Unfortunately, this kind of microphone is incompatible with modern audio inputs which require a voltage from a microphone, not a changing resistance. The first step in the project was to create a circuit that allows the microphone to be used with the USB audio adapter connected to the Raspberry Pi in the phone.

The author is quite proud of the circuit in **Figure 3**. The carbon microphone is connected to the left-hand connection and the microphone input to the right. You can speak into the handset and record the resulting audio on the Raspberry Pi. The circuit contains a 'potential divider', which is a posh name for some resistors wired in series across a potential difference. The potential difference in **Figure 3** is the 5 volts from the power supply. The resistors are R1 and the carbon microphone.

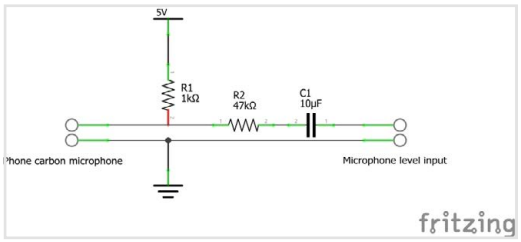


Figure 2
The blue and white wires are connected to the microphone. The green and red wires are connected to the speaker

Figure 3
Increase the value of R2 to reduce the microphone output signal

One of the magical features of electricity is that a potential 'spreads itself out' across the resistance in a circuit. The 5 volts across the potential divider in **Figure 3** is spread across the circuit in a manner proportional to the resistance values. The total resistance is 1,500Ω (1,000Ω for the resistor + 500Ω for the microphone). The 1kΩ resistor is two-thirds of this total, so two-thirds of the voltage is 'dropped' across this resistor. The point where the 1kΩ resistor and the handset microphone are connected should, therefore, be at a voltage of one-third of 5 volts (1.66 volts), the other two-thirds of the potential having been dropped across the 1kΩ resistor.

So, we have a potential divider which contains two resistors: the 1kΩ one and the carbon microphone. When I speak into the microphone, the carbon granules vibrate and the resistance of the microphone changes. This changes the voltage at the point where the microphone and the fixed resistor are connected, generating an electrical signal that represents the sound. The signal goes through a resistor (R2) to reduce its level and then into a capacitor which only lets through the alternating current (the sound signal). This is connected to the microphone input of the USB audio adaptor plugged into the Raspberry Pi inside the phone, and hey presto, we have audio.

Figure 4, overleaf, shows the completed circuit inside the phone. The blue and white cables with the spade connectors are the input signal; the green and yellow wires at the bottom of the board are the output. The red and green wires at the top are the input voltage. The leftmost track on the circuit board →

YOU'LL NEED

- **Raspberry Pi 5** with 8GB of memory
- **A 3D printer** (preferably one that can take a 0.2mm nozzle)
- **NVMe Base with an SSD card** (the author used one from Pimoroni)

If you are adding a microphone input to the Raspberry Pi-powered telephone:

- **2 × resistors** (1kΩ and 47kΩ)
- **10µF capacitor**
- **A small piece of circuit board**

Figure 4
The author has spared you the sight of the soldering underneath the board

Figure 5 (opposite page)
Typing the instruction card was great fun

(the one with the green wires in it) is connected vertically underneath the board; all the other tracks are connected horizontally. It makes sense if you stare at it long enough. And the author has found that it works. The sound quality is not as good as you get from a modern dynamic or condenser microphone, but it is good enough for the voice recognition software we are using. And makes for an authentic telephone voice sound.

SPEECH-TO-TEXT

Now that we have an audio input for our phone, the next thing to do is add some software to convert recorded speech files into text. There are lots of speech-to-text converters available. Some send the sound information into the cloud, where a powerful computer performs the conversion. The author was keen to perform all processing inside the phone and found a library at **hsmag.cc/spchcat** which runs on a Raspberry Pi Zero, albeit a bit slowly. The **spchcat** program is used from the command line. You specify a file (or a sound source), and the program displays the speech that it finds.

```
spchcat --json message.wav > message.json
```

The statement above tells **spchcat** to read the sound recording in the file **message.wav** and create an output file called **message.json** describing any speech that was detected. We can run this from the console, but we really want to want to run it inside the JavaScript program that is controlling the phone. The first thing we do is put the command into a JavaScript string variable:

```
const decodeCommand = `spchcat --json message.wav
> message.json`;
```

The string **decodeCommand** holds the command we want our running program to execute. We can use the **exec** function to run this. It executes a command and then calls a JavaScript function when the command is finished. The **exec** function is a member of the **child_process** module.

```
const { exec } = require('child_process');
```

The statement above imports **exec** into the phone application. The **exec** function accepts a string containing the command and a reference to a function which accepts three parameters – an error message and the output and error streams. The function is called when the command completes (i.e. after **spchcat** has finished running).

```
exec(decodeCommand, (error, stdout, stderr) => {
  if (error) {
    console.error(`Error: ${error.message}`);
    this.decoding=false;
  } else {
    let jsonMessage = fs.readFileSync(`message.
json`, 'utf8');
    let text = this.
decodeSpeechfromJSON(jsonMessage);
    this.decoding=false;
    this.owner.speechDecodedSuccessfully(text);
  }
});
```

The code above shows how **exec** is used to decode the speech. If the **spchcat** command works (i.e. there is no error), the code reads the output file that was produced by **spchcat** and calls the function **decodeSpeechfromJSON** to extract the words from this file. It then tells the owner that the speech was decoded successfully.

LISTEN WITH CONFIDENCE

The **spchcat** program can produce a JavaScript Object Notation (JSON) file which describes what it thinks it has heard. A JSON file contains a text description of an object. In this case, the object contains data fields including a confidence value and a list of the words that were recognised.

```
{
"metadata":{"confidence":-6.96942},
"words":[
    {"word":"how","time":1.24,"duration":0.42},
    {"word":"are","time":1.78,"duration":0.2},
    {"word":"you","time":2.08,"duration":0.04}],
}
```

The phone program presently doesn't use the confidence value, although this could be used to reject speech that might be indistinct. The **words** array contains the words that were detected, along with each word's duration and position in the sample. The function **decodeSpeechfromJSON** converts this array into a string of text.

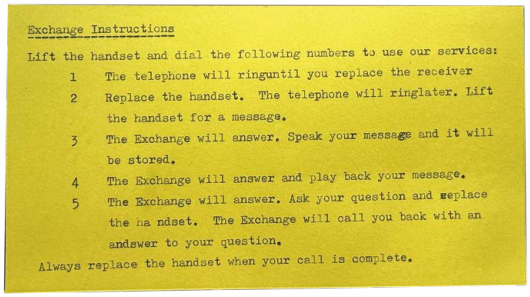
```
decodeSpeechfromJSON(jsonMessage){
  const message = JSON.parse(jsonMessage);
  const text = message.words.map(w => w.word).
join(' ');
  console.log(`Text decoded successfully:
${text}`);
  return text;
}
```

The function parses the JSON string and creates an object that contains the data described by the JSON. It then uses the **map** function provided by the **words** array to extract the word strings from the array and put them into a single string separated by spaces. It displays the decoded text to the console and then returns the text it found. We now have a telephone that can listen to audio and extract spoken text from it. Now we must discover how we can use this to add features to the telephone.

AFFAIRS OF STATE

Figure 5 shows the commands supported by the phone. The original phone software only had two commands. The new phone has much more complex behaviours, and so it was decided to use a state machine to manage it. State machines are worth knowing about. At any given instant, the phone is in a particular state, waiting for events that will cause it to perform actions and then move into a different state.

Figure 6 shows the states used to manage what happens when the user performs a command. The initial state, **REST**, is at the top of the diagram. This state is connected to other states by events which fire at particular times. If the handset is picked up, the phone moves into the **DIAL_TONE** state. You can work your way through the way that the phone is used by examining the states and the events that move them from one state to another. All the states are held in a **stateActions** object.




```
this.stateActions = {
    REST: {
        'Handset picked up': () => {
            this.ringer.ding();
            this.soundOutput.playFile('./sounds/
dialTone.wav');
            return 'DIAL_TONE';
        },
        'Handset replaced': () => {
            this.soundOutput.stopPlayback();
            this.ringer.ding();
```

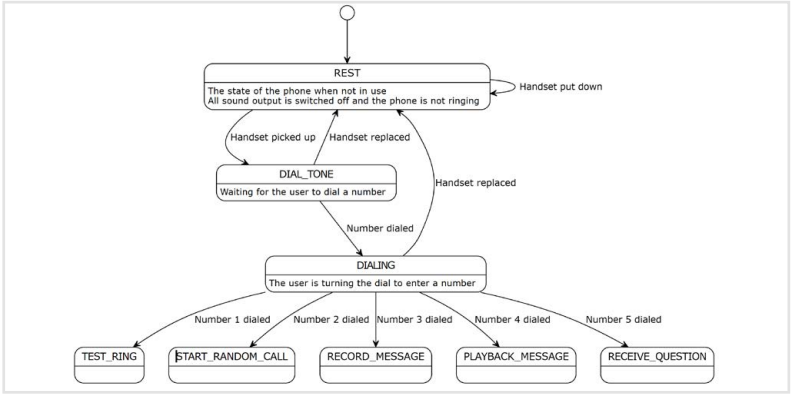


Figure 6
You can use the website at plantuml.com to create diagrams from text descriptions of states and events

```
            return 'REST';
        }
    },
    // Other states go here
}
```

The code above shows the **stateActions** object which represents the **REST** state of the phone. When an event fires, the phone will find the current state and then call the function in that state which deals with the event. The function returns the new state for the phone. If the handset is picked up, the event handler makes the ringer go 'ding' – just like an old phone does – and then plays the dial tone and moves the phone into the **DIAL_TONE** state. The **REST** state doesn't contain handlers for all possible events; for example, turning the phone dial has no effect if the phone is in the **REST** state. Using states makes it easy to change the way the phone works and add new features.

You can use the telephone on its own. It can record and playback messages and respond to requests from the local network. However, it gets more interesting if connected to The Exchange. If you dial 5 on the phone it will record your spoken question, convert it into text and then send it to The Exchange for processing.

AN LLM EXCHANGE

Figure 7, overleaf, shows the insides of The Exchange. The case design has been modified to include the printed text on the side. You can find the STL file for the case in the repository for this project. The Exchange is a Raspberry Pi 5 with 8GB of memory and a solid-state drive (SSD). It runs an LLM that can create answers to questions. So, what does an LLM do? →

QUICK TIP

Small changes to the prompt string can make a big difference to the way the chatbot behaves.

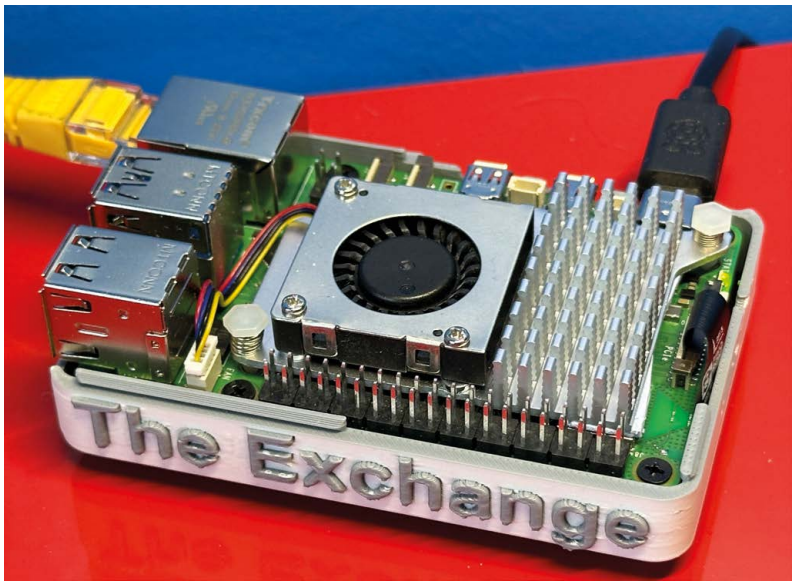


Figure 7
When you ask it a question, the fan comes on

Figure 8
'Bob' is one of the chatbots supplied with the LLM

QUICK TIP

The author has not seen any bad or rude behaviour from The Exchange, but there is no way he would let his seven-year-old granddaughter loose on it on her own.

MODEL BEHAVIOUR

We'll leave it to philosophers to decide what constitutes intelligence and whether or not large language models have it. Essentially they are probabalistic in that it looks at the input, and is trained on large amounts of existing text and tries to decide what is the most likely next bit of text. Is this thinking? Does it matter?

An LLM model is a file containing things which can be matched against inputs to generate outputs and a program that does the matching. The model files used by systems running in the cloud are enormous, but we can obtain smaller ones that can run on an 8GB Raspberry Pi 5 with an SSD. The model file needs to be processed so that it can be used on a Raspberry Pi – there is a link to the procedure for doing this in the GitHub repository for this article.

This model in The Exchange is around 4.5GB in size. The Exchange server users the 'llama.cpp' software to interact with the model. You can find this at **hsmag.cc/llama_ccp**. You can use it to create a 'chatbot' (a program that takes your questions, sends them to the LLM, and then displays the response).

TALKING TO CHATBOTS

Figure 8 shows a console conversation with the 'Bob' chatbot running on the Raspberry Pi 5. He seems to be pretty good on general subjects, although he got the author of the *C# Programming Yellow Book* wrong.

PROMPT, PLEASE

When you use an LLM to create a chatbot, you need to provide a 'prompt string' which is sent to the LLM with every query to 'set the scene' for the query. It looks as if you are providing the model with instructions that will tell it how to behave, but what really happens is that the chatbot finds words that match with the prompt as well as the question you asked. This stops the LLM going off on flights of fancy, something it is prone to doing.

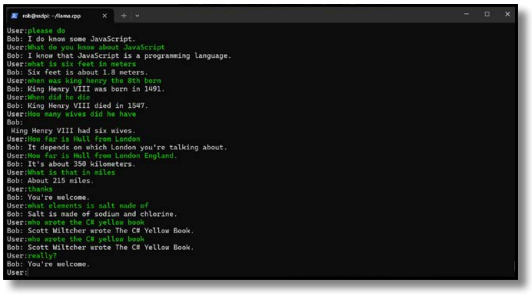
```
let promptPrefix = `Transcript of a dialog, where
the User interacts with an Assistant named
Exchange. Exchange is helpful, kind, honest, good
at writing, and never fails to answer the User's
requests immediately and with precision.

User: Hello, Exchange.
Exchange: Hello. How may I help you today?
User: Please tell me the largest city in Europe.
Exchange: Sure. The largest city in Europe is
Moscow, the capital of Russia.
User:`;
```

Above, you can see the prompt string used for queries to The Exchange. It tells The Exchange how to behave and gives an example of a conversation. The question to be asked is added onto the end of the string which is to be sent to the LLM.

```
question = `${promptPrefix}${question}.`;

let req = {
    method: 'POST',
    body: JSON.stringify({
        prompt : question,
        n_predict: 256,
        temperature: 0.7,
        stop:["User:"]
    })
};
```



> **We'll leave it to philosophers to decide what** constitutes intelligence

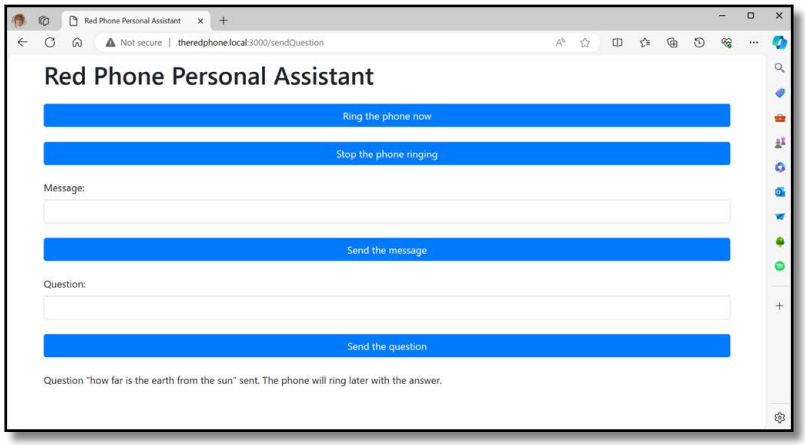


Figure 9
The answer that came back was correct, which is nice

The code above creates a web request which is sent to a Chatbot server which is part of the llama.cpp distribution. The prompt prefix is added to the beginning of the question and sent to the server along with other setting values. The **`n_predict`** setting sets the number of predictions that will be used to build the answer, the **`temperature`** value sets how 'random' you want the answer to be, and the **`stop`** string prevents the chatbot from inventing its own questions from the user and answering them. As soon as the chatbot generates the string **`"User:"`**, it stops generating any more output.

EXCHANGE AND SMARTS

Figure 9 shows the Personal Assistant web page hosted in the phone. This can be used to send messages to the phone from a web page hosted in the phone. You type in the message, press 'Send the message', and the phone will ring immediately and playback the message when the receiver is picked up. The updated version of the phone allows you to type in a question and send it to the phone. The phone will then send the question to the LLM and then ring and speak the answer when it is received.

FUN WITH AN LLM

The service provided by The Exchange is not particularly good. It gets things wrong, doesn't always understand what you asked, and tends to go on about things which have nothing to do with what was asked. But the thing to remember is that this is all happening on small, low-powered devices with no assistance from external computers. You could use The Exchange anywhere, with no need for an external network connection. Furthermore, watching The Exchange get things wrong is actually very interesting, as is playing with the various settings and seeing what happens. The author hopes that you enjoy playing with this and that it improves your understanding of what the technology can and can't do.

TELEPHONE HELPERS

Figure 10 shows all the 'helpers' in the phone application. You can use these in your JavaScript applications. There are helpers for hardware input-output, the LLM, and audio and speech input and output. The entire phone is controlled by an instance of a phone object. When the phone starts running, it creates instances of all the helpers it needs:

```
const SpeechInput = require('./helpers/speechInput');
```

The statement above brings the **`speechInput`** module into the program. A module contains a JavaScript object that you use to interact with the helper services.

```
this.speechInput = new SpeechInput(this);
```

The statement above creates a **`speechInput`** helper object for the phone. The helper is passed a reference to the phone object (that's what the **`this`** keyword means) so that the helper can send messages to the phone by calling methods on this object. When the phone wants to convert an audio file into text, it calls a method in the helper object and passes it the location of the file to be converted:

```
this.speechInput.startSpeechDecode(`./recordings/question.wav`);
```

The statement above shows how this is done. The code in **`startSpeechDecode`** in the helper object sends the **`spchcat`** command to start the speech decoding. When the helper object finishes decoding the speech, it calls a method in the phone to deliver the text that was decoded:

```
this.owner.speechDecodedSuccessfully(text);
```

The **`owner`** property of the speech helper is a reference to the phone it is working for. The phone can then do something with the text (perhaps send it to the LLM). This structure makes it very easy to add new behaviours (just add new helper objects) and also makes it easy to change how a helper works. If you wanted to use a different text-to-speech system, you would just have to change the contents of the **`speechInput`** helper, and the rest of the phone code would remain the same.

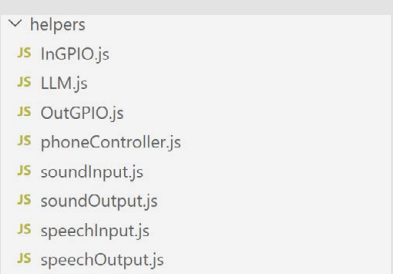


Figure 10
You can use these in your projects just by copying these files into a 'helpers' folder in your applications

Remote control a camera with Raspberry Pi Connect

Dial in to your little computer, wherever it is

Ben Everard

Ben's house is slowly being taken over by 3D printers. He plans to solve this by printing an extension, once he gets enough printers.

Raspberry Pi Connect is a new service from Raspberry Pi that lets you connect to your Raspberry Pi from another computer on the internet. You sign in via the Raspberry Pi website and, from there, you can access the desktop session on your Raspberry Pi and control it as though you were sitting in front of it.

It's similar to how VNC works, with one big difference: Raspberry Pi Connect will help you route your connection through the internet. This means that you can connect to a Raspberry Pi on your home network when you're in a completely different place. Provided the Raspberry Pi and the computer you want to connect to it from are both on the internet, then a connection will get through.

We're going to use this to create a pet camera for keeping an eye on our pets.

To get started, you'll need a Raspberry Pi ID. You might already have one, but if not, you can create one at **id.raspberrypi.com**. Once you've got your username and password, you can set up your Raspberry Pi.

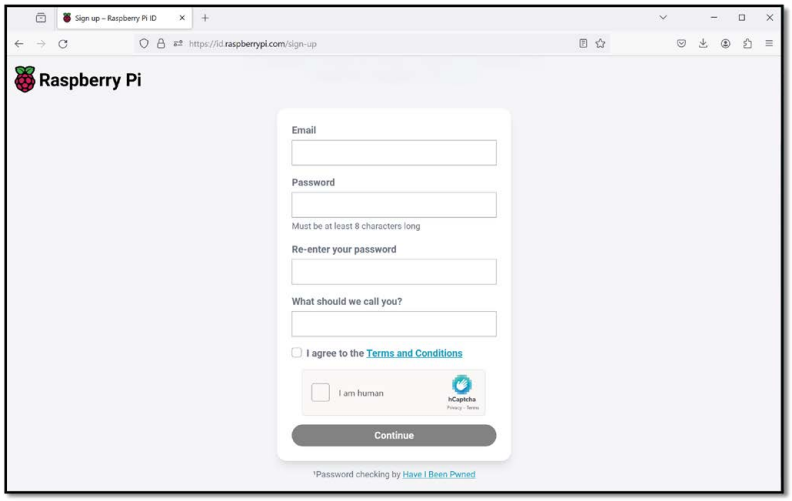
First, you'll need to open a terminal to install the relevant software:

```
sudo apt update
sudo apt upgrade
sudo apt install rpi-connect
systemctl --user start rpi-connect
```

The first two lines make sure that your system is up to date, the third installs the Raspberry Pi Connect client, and the final one starts it. At this point, you should see the Connect logo in the top right-hand corner of your screen. If you click on this, you can select sign-in.

This will open your web browser, and here you can enter the login details you created before. This will add your Raspberry Pi to your Connect account and now you can access it from anywhere.

On a different, internet-connected computer, head to **connect.raspberrypi.com**, and sign in. You should see a list of all connected devices – there should be the one you've just connected (and any others that you've previously connected). Click on Connect



GOING FURTHER

Perhaps the most useful extension to this would be to mount the camera on a pan-and-tilt arm so that you could move it around. Typically, these use two servos and brackets to let you move the camera in two axes.

There are a few kits available with this, or you can go the DIY route.

If you want to take things even further, you could add some way to interact with your pet. For example, you could mount a laser pointer on a servo so you can wiggle it, or perhaps move a string with a cat toy on it.

and a new window will pop open. If the Connect button isn't there, it means that the Raspberry Pi is connected to your device but not available to connect to. Make sure that you've signed in on that device and that it's powered on.

Once it's signed in to your Raspberry Pi – this might take a few seconds – you should see the desktop of that computer open in the web browser window. You can now control the mouse and keyboard remotely, just as if you were using a mouse and keyboard physically connected to the Raspberry Pi.

At this point, you can use the machine however you like. You might find this easy for helping friends and family with technical problems; you might find it an easy way to keep tabs on your home server. However, in this article, we're going to use it to create a pet camera. This is basically, a camera that we can set up at home and connect to keep an eye on our pets.

> **Raspberry Pi OS comes with a few tools for working with** the cameras

ON TEST

Our two test cats for this article are both kittens about nine months old, named Peach and Moon. Their welfare was a top priority while testing the software, and we can confirm that no cats were harmed in the making of this feature (though Peach did scratch the author, and Moon knocked a plant pot off the windowsill).

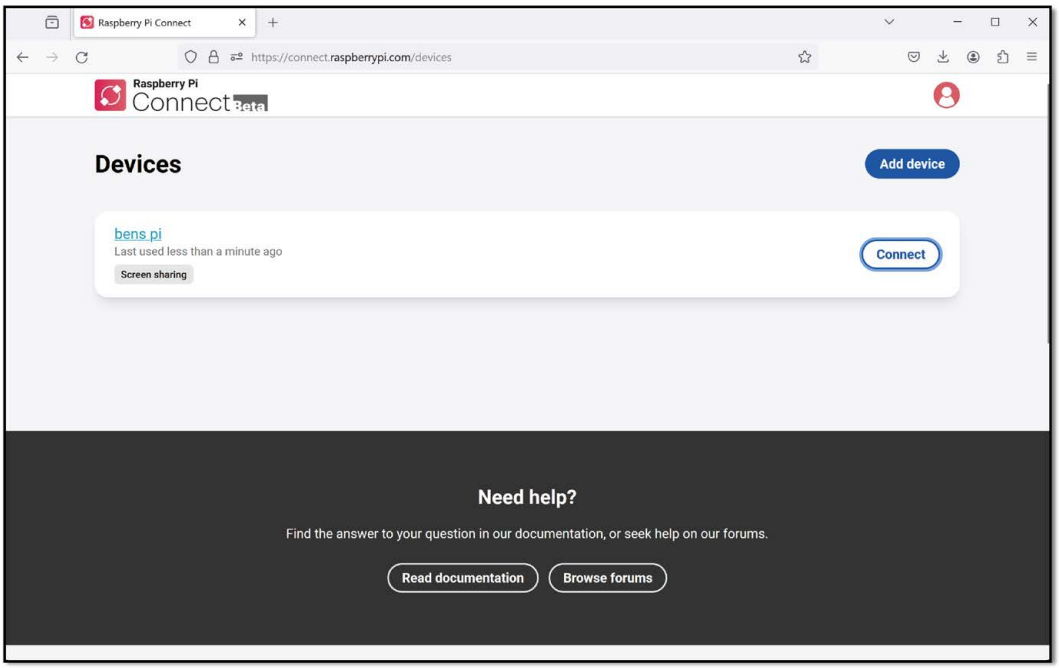
The first thing you need is a Raspberry Pi Camera connected to your board. It's safest to do this with the power off, so turn off your computer if it isn't already. You can now connect the camera cable to the camera port on a Raspberry Pi 4, or either of the camera/display ports on a Raspberry Pi 5.

Raspberry Pi OS comes with a few tools for working with the cameras, but they're all command line-based. There is nothing stopping you using these for the pet cam, and simply logging into the desktop and using the terminal. However, we'll be doing something a little more user-friendly.

We're going to use the Picamera2 WebUI Lite interface created by James Mitchell (aka monkeymademe on GitHub). This runs a web server that serves up a web page that lets you view and control the camera. →

Above Left
A Raspberry Pi ID can be used for various activities, including signing up to get the PDF download of HackSpace magazine a month early

Above
This pair are not as innocent as the image may suggest



Above
On the Connect page, you should see an entry for every Raspberry Pi you've added to Connect

This highlights the problem that Raspberry Pi Connect solves. After all, you may think, if the Raspberry Pi is serving up a web page, surely we can view this as we can view other pages on the web? The answer is usually (but not always) no, and for reasons that aren't particularly straightforward.

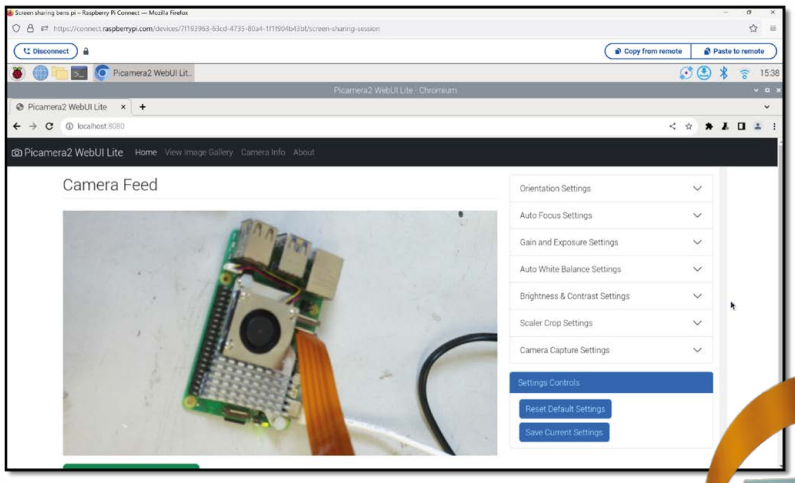
The first problem is addressing. You can send a message to any computer on the internet with an IP address. These addresses can either be version 4 (which is a series of four numbers separated by dots), or version 6 (which are alphanumeric strings separated by colons). For most of the history of the internet, version 4 has been the most popular. Given that IPv4 addresses are 32 bits long, there are just over 4 billion possible addresses. In a world with 9 billion people, where many people have lots of devices connected to the internet, this is a problem. One of the solutions to this is Network Address Translation, or NAT. This is where a local network (such as your home or office network), assigns a set of private IP addresses. These often start 192.126 or 10.10. There can be thousands, or quite possibly millions of devices with the IP address 192.168.0.1, and it's absolutely fine because they are only accessible on their local network. Computers outside of this can't send them messages.

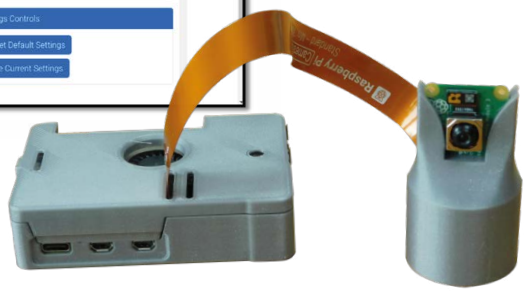
Computers on these private networks can send messages to the wider world through the magic of NATs.

There are solutions to this, but typically they involve changing settings on your router, and this is a bit technical, and can potentially open you up to security problems.

Raspberry Pi Connect takes care of this headache, and gives you the desktop via the internet. We can use this desktop to access the web page running locally. Let's take a look at how to do this.

You need to run the following commands on the Raspberry Pi, but it makes no difference if you run them using a keyboard and mouse physically attached to the Raspberry Pi, or on another computer via Connect. Either way, open up a terminal and run





Above
Raspberry Pi OS running in Firefox on Windows

Right
You can tidy everything up with a 3D printed case

the following:

```
git clone https://github.com/monkeymademe/
picamera2-WebUI-Lite.git
cd picamera2-WebUI-Lite
python app.py
```

You can now open a web browser in the Connect desktop, and point it to **localhost:8080**.

You should see the output of your camera, and there are controls for managing it.

The problem with this is that the web server will stop if you restart the computer. You can set it to automatically restart by running the following command:

```
crontab -e
```

This opens the configuration file for Cron, which is a bit of software that handles regular operations. Select to use Nano (if you haven't used this before), then scroll to the bottom, and enter the following:

```
python /home/ben/picamera2-WebUI-Lite/app.py
```

…replacing 'ben' with your username. Press **CTRL+X** to save and exit. The camera server will now start automatically if you restart your computer.

SECURITY CAMERA

Our system works well for a simple, remotely viewable camera such as a pet camera. However, there are far more powerful options out there if you want more security camera-type features. For example, motionEye lets you perform particular actions when it detects movement in a frame.

Do be aware that if you are recording people, you will need to follow local laws on data protection.

FINAL STRETCH

That's the software set up. The last thing we need is to tidy up the hardware. We don't want to leave a bare Raspberry Pi sitting around the place, or it'll get damaged, and we need a way to mount the camera.

There's a huge range of options for both of these, and you may already have the bits you need. We opted to print a Raspberry Pi Camera Holder from the Raspberry Pi account on Printables (**hsmag.cc/camholder**), and a Raspberry Pi 5 Case by Hasan Yildiz (**hsmag.cc/5case**).

With these, we can set up our pet cam wherever we want, and keep an eye on this pair of mischievous felines.

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HackSpace
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FIELD TEST

HACK | MAKE | BUILD | CREATE

Hacker gear poked, prodded, taken apart, and investigated

ONLY THE BEST

Growing plants and capturing wildlife

A collection of electronics related to gardening

By **Marc de Vinck**

We've circled the sun one more time! Daylight hours and the temperatures are increasing. Spring has finally arrived. You've survived a long winter building your projects and keeping warm, but now it's time to think about what to build next. And it's a perfect time to start thinking about your garden, and how you might build something to make it a little smarter, easier to understand, or just capture the wildlife that visits. I've looked at gardening products before, and I'll certainly look at them again, because I just love to revisit the topic every spring. Having recently moved, I've been planning a new garden. And, unlike our other gardens in the past, this one has access to some power and a little more space, so a few automations might come in handy and would be easy to implement. Another thing that we have experienced at the new place are new types of critters that have been on the prowl looking for food. I really don't mind the occasional chipmunk, or even bunny, but we've also seen bears, bobcats, and even coyotes, all of which I find fascinating and would love to capture on a camera, documenting their regular visits.

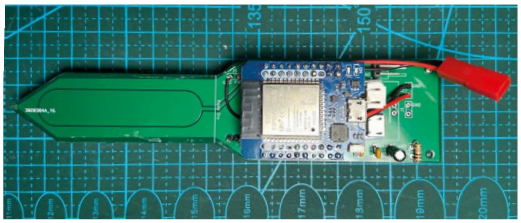
In this Best of Breed, I will be looking at garden-related products that will hopefully inspire you to build your own smart-garden. And, also a few products that will help you document any visitors that might be coming by for a little nibble.

Naturebytes Wildlife Camera Kit vs Solar Powered Soil Moisture Probe

THE PI HUT $114.60 | thepihut.com **TINDIE** $40 | tindie.com

The Naturebytes Wildlife Camera Kit is what really inspired this Best of Breed. I wanted some kind of trail camera, but I didn't just want an off-the-shelf variety because I have some customising that I want to do. So, naturally, I looked for a Raspberry Pi-based system, and this kit really impressed me.

At the core of the Naturebytes kit, you'll find a Raspberry Pi A+. Couple that with a PIR sensor, camera module, SD card, and well-designed, waterproof enclosure, and you've got yourself a very customisable and easy-to-use wildlife cam. The case is IP55 certified, has a Fresnel IR lens for optimising any motion detection, a padlock loop, and no soldering is required. Just keep in mind that this kit does not include any power, so you might want to pick up a battery pack or, in my case, a solar panel and inverter.



This Solar Powered Soil Moisture Probe, designed by The Garden Tinkerer in Canada, uses an ESP32 to broadcast your soil's moisture level over Bluetooth Low Energy (BLE) to your Home Assistant.

Once assembled, the moisture sensor will take multiple readings for one minute, broadcast the readings, and then enter a deep sleep for four hours. It will repeat this process indefinitely, as long as it receives power.

Speaking of power, the creator has options from buying just the sensor and PCB, to complete kits that include the ESP32, a battery pack, and a solar panel, making power essentially a non-issue. This certainly must be the most robust soil moisture probe I've seen in a while, if not ever, but if you take your gardening seriously, and you already have ESPHome running for other automations, this might make for a great choice to add to your garden.

VERDICT

Naturebytes Wildlife Camera Kit

A well-thought-out kit.

9 /10

VERDICT

Solar Powered Soil Moisture Probe

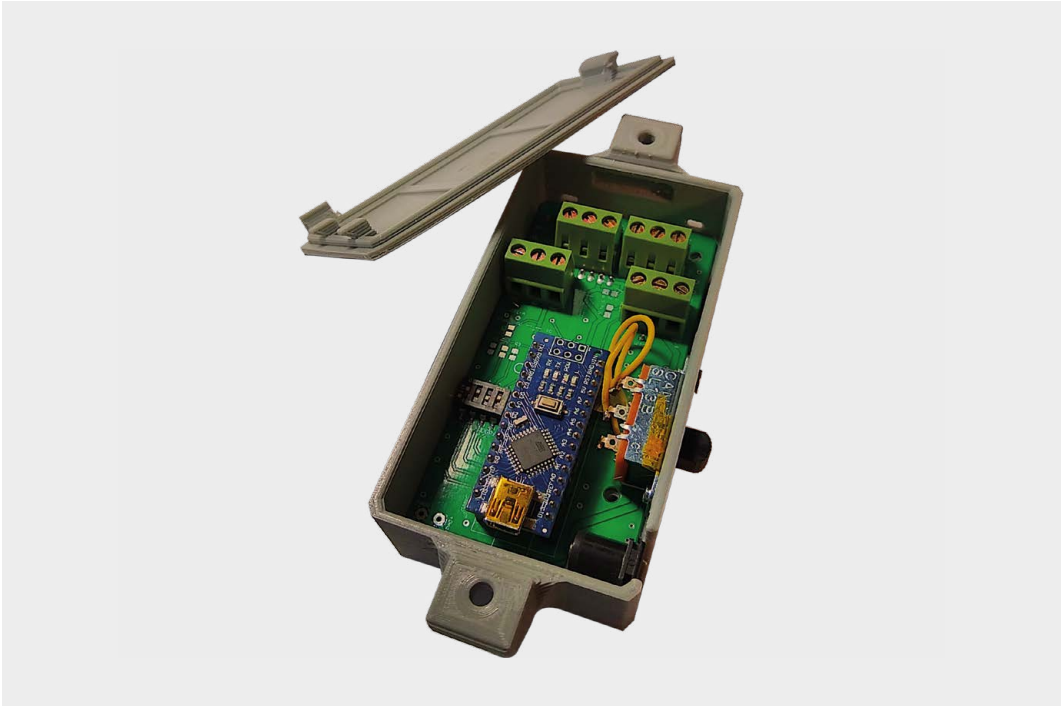
Pricey, but how many moisture probes have integrated BLE?

8 /10

BEST OF BREED

GPOD – A NeoPixel Grow Light Controller

TINDIE $36 | tindie.com



Not everybody has the space to garden outside, or maybe you just start your seedlings early in the year and live in a colder climate, so a little indoor growing is required. And that's where the GPOD Controller comes into play for your indoor plants and seedlings. It uses an Arduino Nano and 5 volts to illuminate some multicolour LEDs, giving your plants 14 hours of illumination throughout the day. You can order just the bare PCB, a full kit, or even fully assembled. This is a great place to start learning about controlling smart LEDs and programming. And, for those wondering, how can an RGB LED be a proper grow light? You're right, they might not be the 100% perfect grow light for plants, but just keep in mind this kit does work, albeit not as effectively as some other grow-specific light options. And you can always expand the system to control specialised UV sourcing designed for plants.

VERDICT

GPOD – A NeoPixel Grow Light Controller

Useful for DIY germination.

7 /10

Night Vision Camera for Raspberry Pi

PIMORONI $23.65 | pimoroni.com

Nothing is going to sneak by you at night if you have the Night Vision Camera for Raspberry Pi. The module is available in either 70° or wide-angle 160°, and has built-in IR LEDs that allow you to see in complete darkness without any visible light.

The camera has a 5MP sensor with a full-size cable connector. It captures 1080p video at 30 frames per second (fps). The higher frame rate, you can also lower the resolution to 720p and capture video at 30 fps, or at a high frame rate of 90 fps at 480p. They include two different types of cables, allowing you to connect it to a Raspberry Pi Zero W or a standard-size Raspberry Pi. This is exactly what I was looking for adding to my garden, and backyard in general, so I can see what's been going on with the local wildlife at night.

VERDICT

Night Vision Camera for Raspberry Pi

Perfect for catching late-night raiders.

9 /10

BEST OF BREED

Raspberry Pi Debug Probe

RASPBERRY PI $12 | raspberrypi.com

At some point in your journey with electronics (whether garden-based or not), you'll hit a roadblock and wish there was a better way to look at what exactly was going on with all those GPIO pins.

Fortunately for all of us, the creators of the Raspberry Pi have also designed the Raspberry Pi Debug Probe. It's a complete hardware solution for Arm-based microcontrollers and is powered by an RP2040. It makes it easy to probe the logic of a Raspberry Pi through your PC, Mac, or Linux computer.

The probe features both a processor serial debug interface and a UART interface. Both interfaces connect to the Raspberry Pi 3-pin debug connector. It was designed to be used with a Raspberry Pi, but it also uses standard UART and CMSIS-DAP interfaces over USB, so it can debug any Arm-based microcontroller that has an SWD port running at 3.3V or with a simple USB to UART cable. If you need to troubleshoot your Raspberry Pi, then this is an affordable must-have tool.

VERDICT

Raspberry Pi Debug Probe

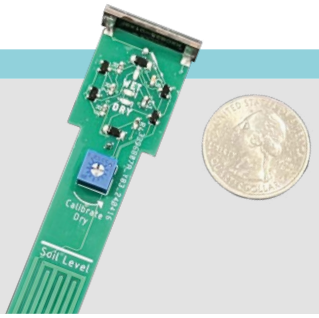
A great addition to your lab.

10 /10

SOLAR-POWERED SOIL MOISTURE SENSOR

TINDIE $29.99 | tindie.com

If you just need a simple reminder of when your plants are thirsty, then the solar-powered soil moisture sensor from AnalogSolutions has a perfect solution. This elegant sensor doesn't require any power, thanks to the on-board solar panel, and it doesn't chirp like many other sensors. It just lights up a simple LED to let you know it could use a drink!



REVIEW

Ploopy headphones

Build your own headphones

PLOOPY ◈ **approx £75 plus tax and shipping** | **hsmag.cc/ploopy**

By **Ben Everard**

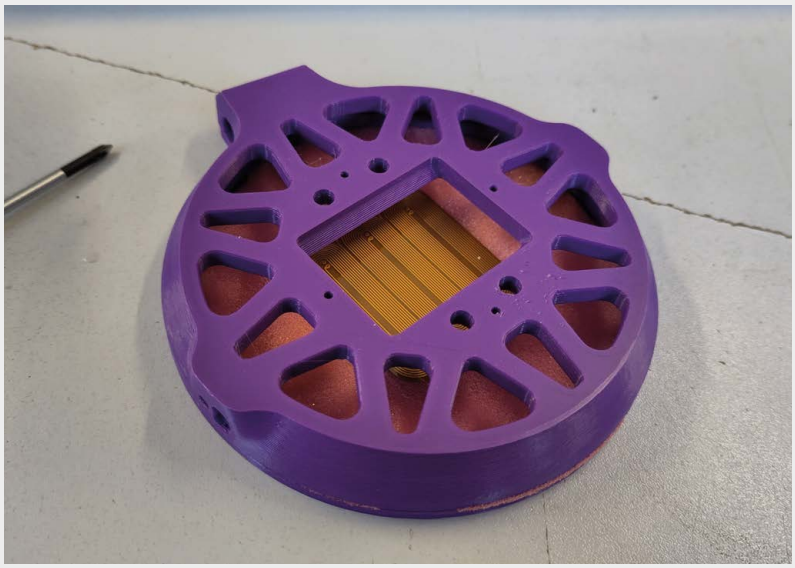
Below ◈
The drivers before the magnets were put in – you can see the coil etched into the PCB

BUY IF

You want open-source headphones

Open-source – check. 3D-printed – check. Self-assembled kit – check. These headphones tick a lot of boxes for us. They're open-source all the way down – that means there are Gerbers for the electronics, STLs for the 3D-printed parts, source code for the software, and full instructions on how to put it all together.

However, before we dig in deeper, there's one part of this review that's so overwhelmingly large that we might as well get it out right at the start: these headphones don't work with phones. Well, not reliably. While they use USB-C – like most modern phones – they draw too much current. They do work as long as you keep the volume down; however, the volume has to be lower than the level we like our headphones to be at (and this reviewer doesn't have his headphones particularly high to start with). How low exactly depends on the song. They seem to particularly struggle with the anvil strike sound on *Hammer and the Anvil* by The Longest Johns (don't judge us; we live in Bristol).

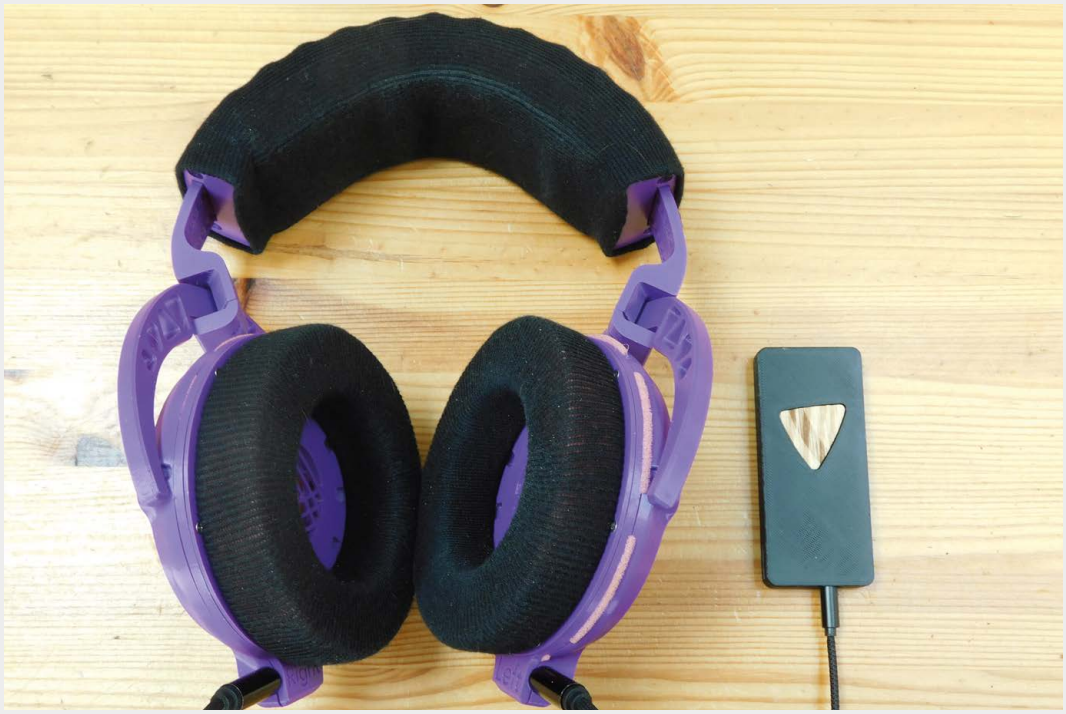


If you're really keen, you could splice a USB-C cable so that it takes power from one source and data from another. Then you'd be able to plug it into both a phone and a USB battery pack at the same time. However, really, unless the open-source or 3D-printed nature of this is particularly important to you, it's probably worth getting a different set of headphones if you want to use them with your phone.

So, with that out the way, let's take a closer look at the headphones.

We got the self-assembly kit and put it together ourselves. The first surprising thing was the lack of any drivers. We'd naively assumed that headphones would start off with a set of mini speakers and build up from there. Many probably do, but not these ones. Instead, you get a flex PCB with a coil printed on it and some magnets to slot into a 3D-printed case. Essentially, you have to assemble the drivers yourself. In other words, you have to start from scratch.

None of the assembly is very tricky. It does start with some surface-mount soldering, but it's straightforward, and it should be possible even



Above Left
They're big, bold, and sound great

for someone who hasn't done any surface-mount work before.

The instructions are clear throughout, with videos used to show the trickier tasks. Our only criticism is that you do need to flatten some foam – basically, leave it under a heavy book for a long time. It'd be useful to know this before we started building them so we could do it in one go.

One thing to note on this is that, while you can build them from scratch, you can only buy them as a full kit or a built pair. You can't buy, for example, just the electronics and 3D-print the parts yourself.

MUSIC TO YOUR EARS

While building headphones is fun, this kit only really has any value if they are useful once they are fully made.

They're absolutely enormous, and 3D printing isn't exactly the lightest manufacturing technique, so they're a bit heavy – 409g to be precise (and that's not including the cables – there are a lot of cables). The wide band over the top does a good job of distributing the weight across the head, and we found them reasonably comfortable; however, you can't really get away from the fact that they are big and heavy. This would be far more of a problem if we wore them to walk around, but given that we can't use them with our phone, that's not an issue we have.

While the size makes them cumbersome to wear, it does give them better acoustic properties, and these sound great. We've seen comments online about these sounding like headphones costing multiple hundreds of pounds. Unfortunately, we've never had multiple hundreds of pounds to spend on headphones, so we can't compare them in that way. However, they do sound great across the frequency range. They can reproduce bass unlike any headphones we've used before, and still sound great at the high-end.

Another issue with their size is their appearance. This is amplified by the fact that they come with all the 3D-printed parts in one colour. This reviewer is planning on supplementing his with a few parts in different colours – this should be entirely straightforward since the STL files are available. Maybe a bit of sparkle from some Galaxy Black would make them more appealing?

The open-backed planar design means you can hear background noise around you – if you're trying to block out the sound of co-workers, children, other commuters, or general hubbub, these might not be for you.

These headphones are utterly preposterous. However, we love them. We can't believe that something we made with our own hands sounds so good. Frankly, it's a bit hard to believe that you can make a driver with a flex PCB and some magnets, but here we are.

All that said, they are only good for a very specific use case: sitting down and powering them via a plugged-in USB-C audio device. While they're certainly not for everyone, we've no doubt that there's a market there. ◻

AVOID IF

You want to move around

VERDICT

Open-source and great-sounding, but not very portable.

9/ 10

REVIEW

The Coming Wave

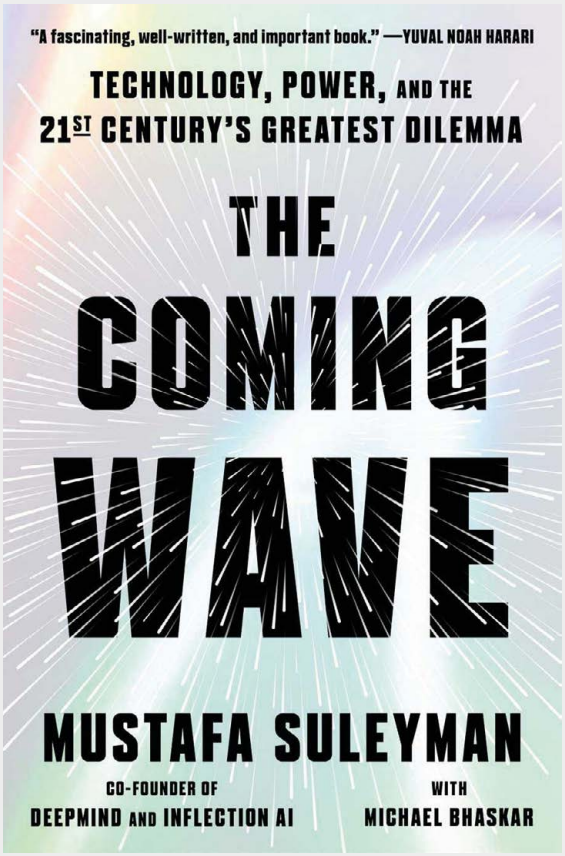
Is humanity doomed?

MUSTAFA SULEYMAN ◈ £25 | the-coming-wave.com

By **Ben Everard**

BUY IF

You are more pessimistic than us



Right ◈
Is humanity doomed? Probably. But not in the way that this book says it is

There's something comforting about reading a book about an impending human-made disaster that isn't global heating. Maybe a rapidly-becoming-inevitable climate catastrophe won't be the thing that finishes off civilisation after all. Maybe, if Mustafa Suleyman is to be believed, artificial intelligence (AI) or biotech will get us first.

Suleyman makes the argument that AI is developing at such a rapid pace and is applicable to so many things that it's very soon going to have the potential to do very harmful things to society, from empowering despotic regimes to enabling terrorists to perform ever-more horrific acts. Also, he throws in some things about bioengineering, but this always feels vague and like an afterthought. Quantum computing is also occasionally mentioned.

Suleyman starts by saying that containment – that is, the restriction of a technology – never works. If something is possible, it will end up being done regardless of whether or not it is permitted. He supports this with a handful of cherry-picked examples, before making the surprising claim that nuclear weapons are the only technology that has ever been successfully restricted.

Suleyman then proceeds to regurgitate a few years' worth of Silicon Valley press releases about how powerful the technology is about to become.

He says that we don't have to believe that all this is possible in the future for his argument to be true, but as someone who receives a lot of tech industry press releases, this reviewer is particularly sceptical about claims of technologies 'just around the corner'.

He never quite sets out exactly what he feels the future problem will be, but most of the times that he tries to, his concerns seem to rest somewhere around the fact that large language models (LLMs), like ChatGPT, will soon become more intelligent than people. This, at least, seems to be the thrust of the solution he proposes in the final chapter.

Finally, Suleyman concludes with the solution: containment. The same containment that he dismissed at the start, only this time we'll do it with our fingers crossed. Maybe it'll work this time if we really mean it. However, it is worth pointing out that he seems to view the word containment as meaning something subtly different at the end than how he used it at the start. In the first chapter, when he talked about how it never worked, he used the word to mean the complete removal of a technology. Here, he uses it to mean something much closer to regulation. He doesn't acknowledge this change in use of the word.

When used this way, it's obvious that containment has been successful many times. Guns, cars, chemical weapons, electrical installations – even medieval technology such as swords and crossbows – are regulated, and while they do still have their dangers, they cause far fewer calamities than they otherwise would. The lesson of history, then, isn't that regulation isn't successful, it's that it's imperfect, frustratingly slow, but often ultimately effective.

We are perhaps being a little glib here. There's no doubt that Suleyman is a highly intelligent person and is very well-placed to both see and understand the potential risks of AI. There is also no doubt that AI has progressed significantly in the previous couple of years, and it will probably continue to do so. While a civilisation-ending catastrophe is a bold claim, there are undoubtedly big changes coming.

AI is putting people out of jobs, though how far this trend will continue remains an open question. Suleyman very briefly touches on the potential for human suffering caused by increased unemployment, though this may end up being a more thorny question. Whether or not this trips over into Ludd-style rebellion, there is the possibility (perhaps even likelihood) of AI creating real suffering in communities. For example, regions where call centres account for a large proportion of the employment. Suleyman's containment of advanced AI will not help them.

THE END IS AI?

The rate of technological change feels like it's increasing, with whole new types of technologies springing up all the time. Any one of these technologies could have catastrophic consequences for the human race. It's surely only a matter of time until one of them does finally finish us off.

That previous paragraph feels a little scary, but it's perhaps comforting to realise that this sentiment would feel familiar to many people at any point in the past 500 or so years. Many technologies have come and shaped our world and, so far, we've always been able to adapt to them, or them to us. Maybe we'll get unlucky this time and AI will be the one that finally does us in, but there's nothing in this book that convinces this reviewer that it's more dangerous than many others.

It will, of course, create winners and losers – new technology always does. There will be a champagne reception in some areas and unemployment in others. It will be unfair, and it's unlikely that those who lose out will be adequately supported. This, however, is not the civilisation-ending disaster Suleyman is concerned with in this book.

We're not sure if this makes us optimists or pessimists about AI, but after reading *The Coming Wave*, our money's still on it being climate change that finishes us off. ◻

AVOID IF

You're more concerned about the implication of current technology than the as-yet undeveloped future products

VERDICT

Passionate and articulate, and ultimately unconvincing.

7/10

CROWDFUNDING NOW

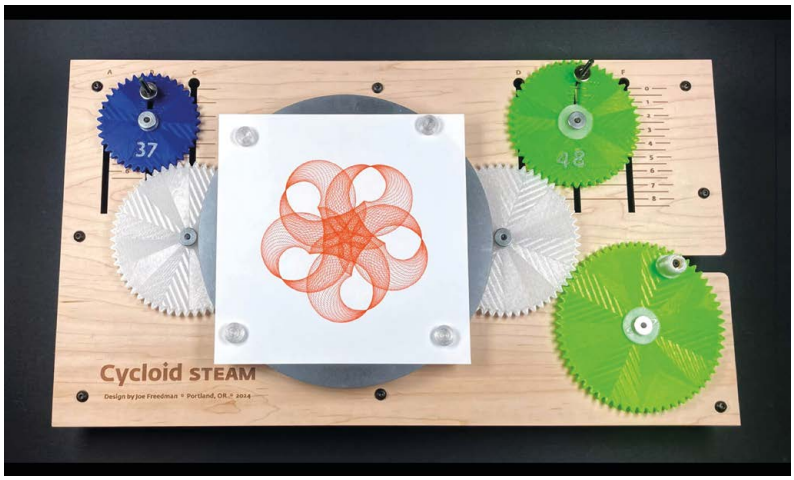
Cycloid STEAM/DIY

Beautiful pictures that are probably mathematical

From $45 | **hsmag.cc/cycloid** | **Delivery:** August 2024

Like many people, this writer enjoyed playing with a Spirograph when he was a child. This was one gear that was placed inside another, similar to a planetary gear. You put a pen in a hole in the smaller gear, then traced it around to create a flower-like pattern. The results looked mathematical, but I didn't understand the maths behind it.

The Cycloid STEAM/DIY kit takes this up another level. This more complex machine uses linkages as well as gears to create drawings that look mathematical, but we still don't understand the maths behind it. The results – at least according to the Kickstarter video – are intricate and more beautiful than anything we were able to create on a Spirograph.



BUYER BEWARE

When backing a crowdfunding campaign, you are not purchasing a finished product, but supporting a project working on something new. There is a very real chance that the product will never ship and you'll lose your money. It's a great way to support projects you like and get some cheap hardware in the process, but if you use it purely as a chance to snag cheap stuff, you may find that you get burned.

Wee Noise Makers PGB-1

Who needs a Walkman when you can make your own tunes on the go?

From $249 | **hsmag.cc/pgb1** | **Delivery:** Jan 2025

It seems to us that there's an unnecessary amount of musical instruments. There's a lot out there already – surely musicians can come together and agree that one of them is the best, and everyone can get that one. However, when we suggest this to people who play music, they seem to get a bit angry.

There is now one more musical instrument: the PGB-1 by Wee Noise Makers. It's a sequencer, so you can assign various notes to the 16 different slots, and then apply different effects or sound engines to them. You can even hook it up to your various other MIDI instruments and make them make lots of beeps and boops.

It looked very impressive to us, but we're not musicians, so can't really comment on whether this will be the one that the musical community can unite around, or if we're doomed to forever have N+1 different instruments. ◻

next month

issue #80 ON SALE 27 JUNE

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3D-printed guitar neck

3D printing is great for all sorts of applications, but building a guitar neck isn't necessarily one of them. We tried to print a ukulele once and got it completely wrong; examples we've seen, such as the Prusacaster, keep the standard wooden neck and 3D-print the body (and you can see a unique interpretation of a 3D-printed guitar in this issue, on p44.)

However, just because it's never been done doesn't mean that it can't be done. Jón Schone has made this guitar neck using a Creality CR-30 belt printer, which effectively gives you an infinite X axis, making longer prints possible than on a standard printer. It's also capable of printing layers at a 45-degree angle, which you can see if you look carefully. The thing Jón has done that we forgot about is to add a truss-rod – a threaded rod that runs along the length of the neck and adds strength. Keep an eye out to see how this print develops: Jón has grand plans to build an entirely 3D-printed electric guitar.

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