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HackSpace

TECHNOLOGY IN YOUR HANDS

hsmag.cc | August 2024 | Issue #81

50 ELECTRONICS PROJECTS

Design and build your own circuits, from LEDs to microcontrollers

Aug. 2024
Issue #81 £6

KICAD LASER CUTTING **PIANOLA** PICO

Welcome to HackSpace magazine

In the past five years or so, both the price and ease of use of microcontrollers have plummeted. It's now at a point where popping a small programmable board into a build is something you can do almost without thinking about it. A few quid on parts and a couple of dozen lines of code can turn something static into something interactive.

In this issue, we're looking at 50 different ways you can do this. Some might be familiar to you, and hopefully some will encourage you to try something new. Let's get electric. It's easier and cheaper than you might think.

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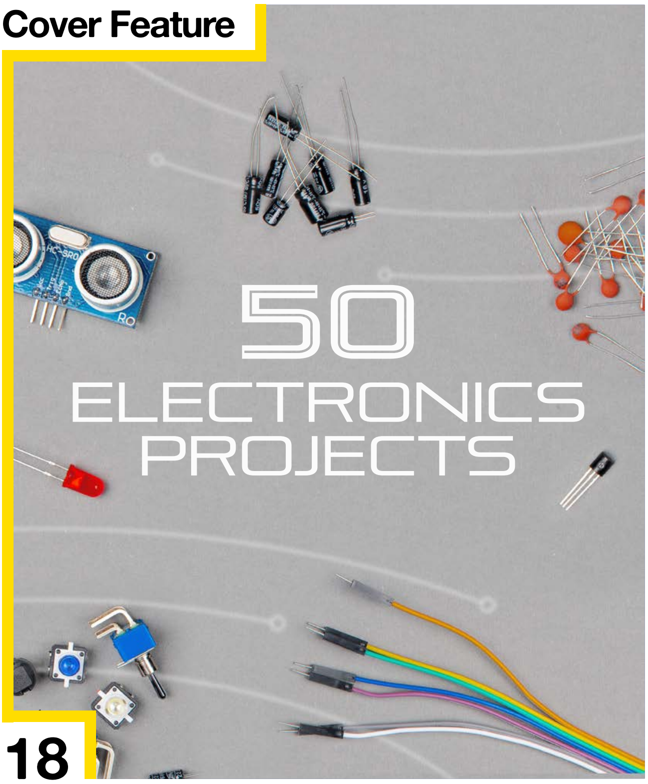

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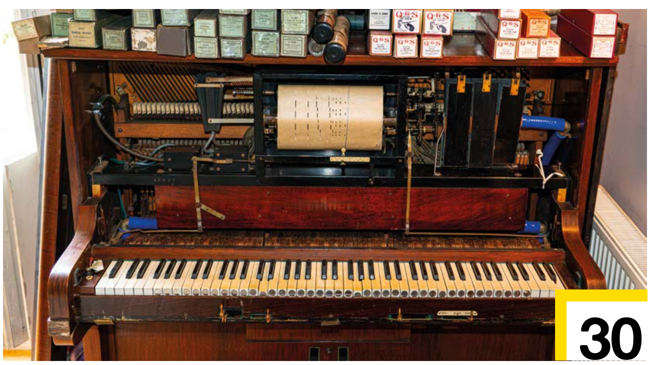

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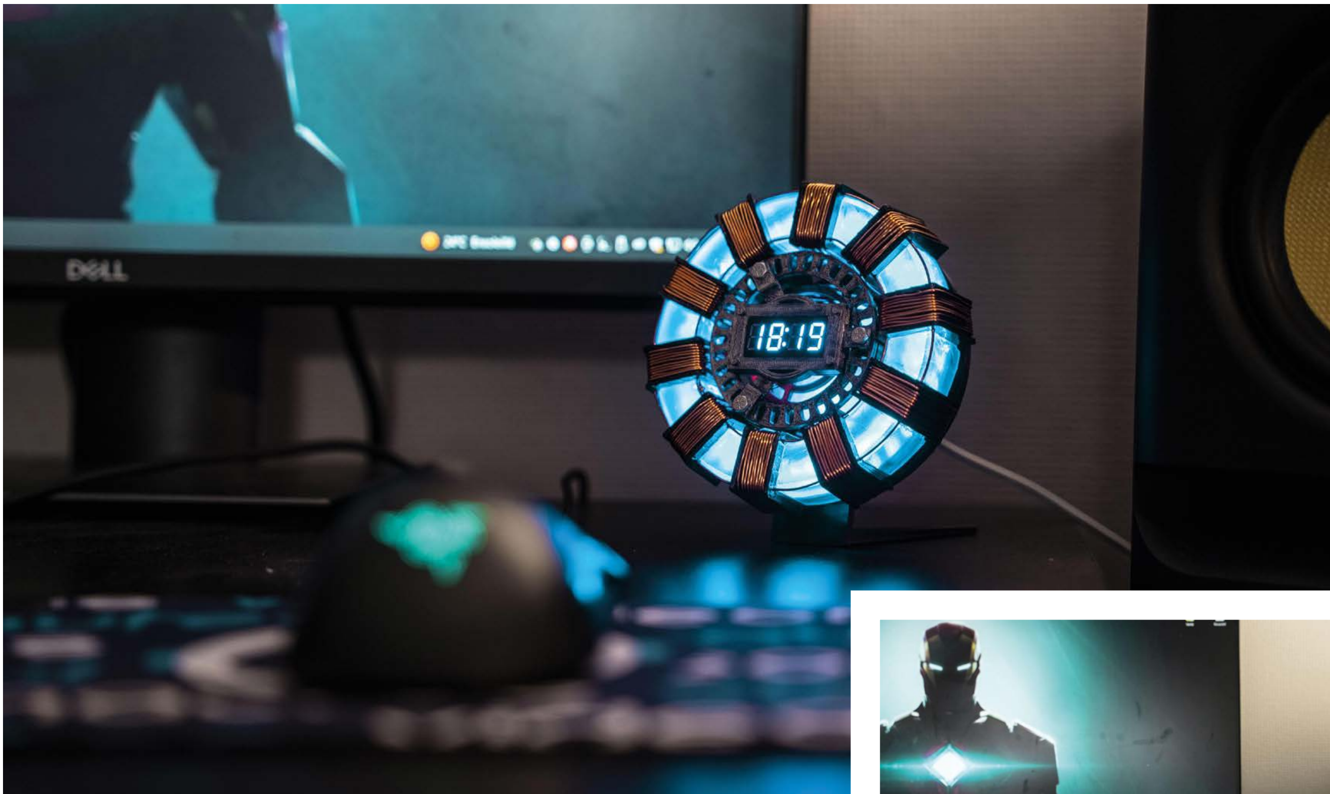
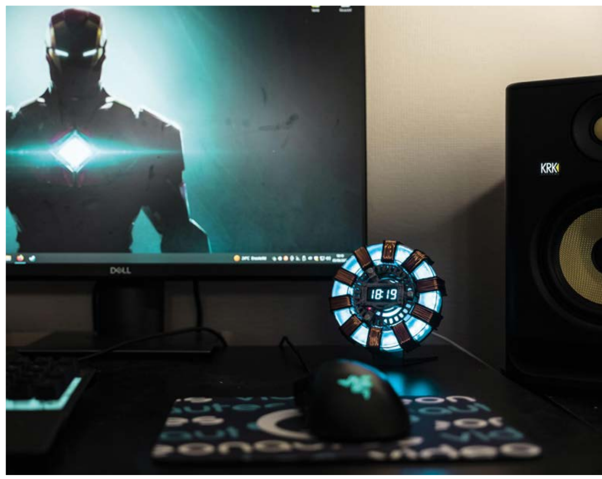
REGULAR





Arc reactor alarm clock

By **Jéjé l'ingé**

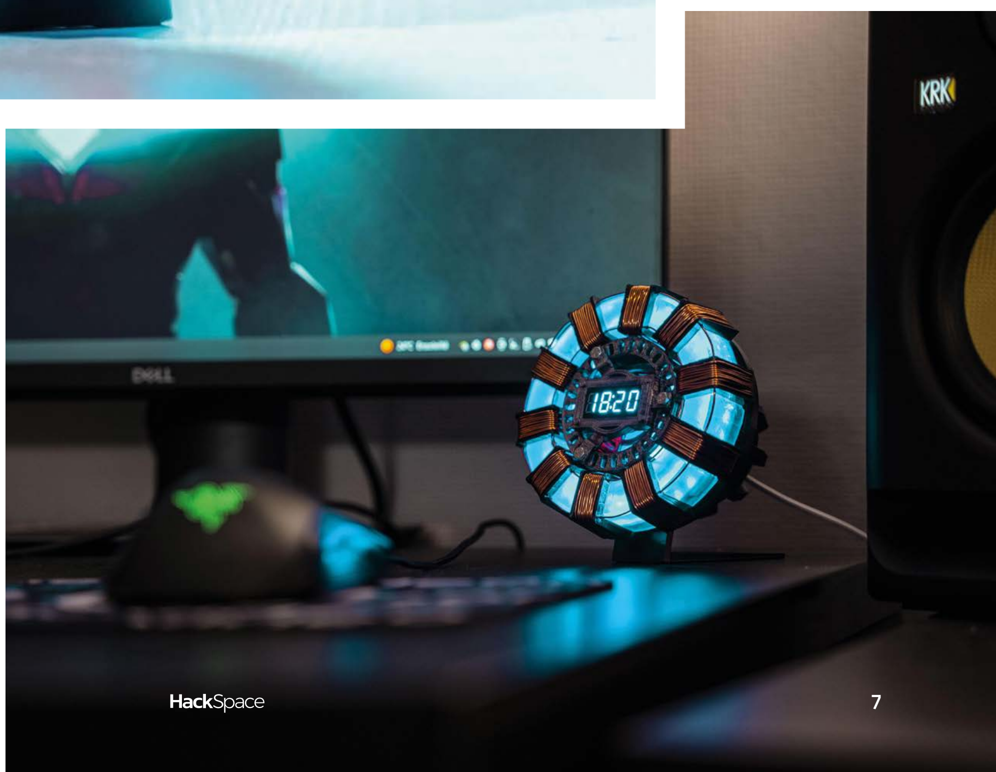
hsmag.cc/ArcReactorAlarmClock

We are – or at least, we used to be – huge fans of the Marvel cinematic universe and all the props and cosplay that it has given us over the years. One classic of the genre is Iron Man's arc reactor — the glowing power source that sits in Tony Stark's chest and powers his special suit. It's almost a cosplay rite of passage to build your own arc reactor, so here's our favourite implementation: an arc reactor that's also an alarm clock.

As an arc reactor is basically a round, glowing thing, it should come as no surprise that Jéjé starts with an off-the-shelf NeoPixel ring, powered by a Mini ESP32. The structure that holds the electronics is printed out of black and transparent PLA, and there are ten coils of copper wire – these don't do anything, but they do look extremely cool.

Jéjé's provided detailed instructions for anyone who wants to make their own version, so you too can tell the time like a fictional genius billionaire playboy philanthropist. □

Above You can power this clock from your computer's USB cable, or from a phone charger – which, to be honest, is probably a little more use for an alarm clock, given that we tend to not to have our computer out when we're asleep



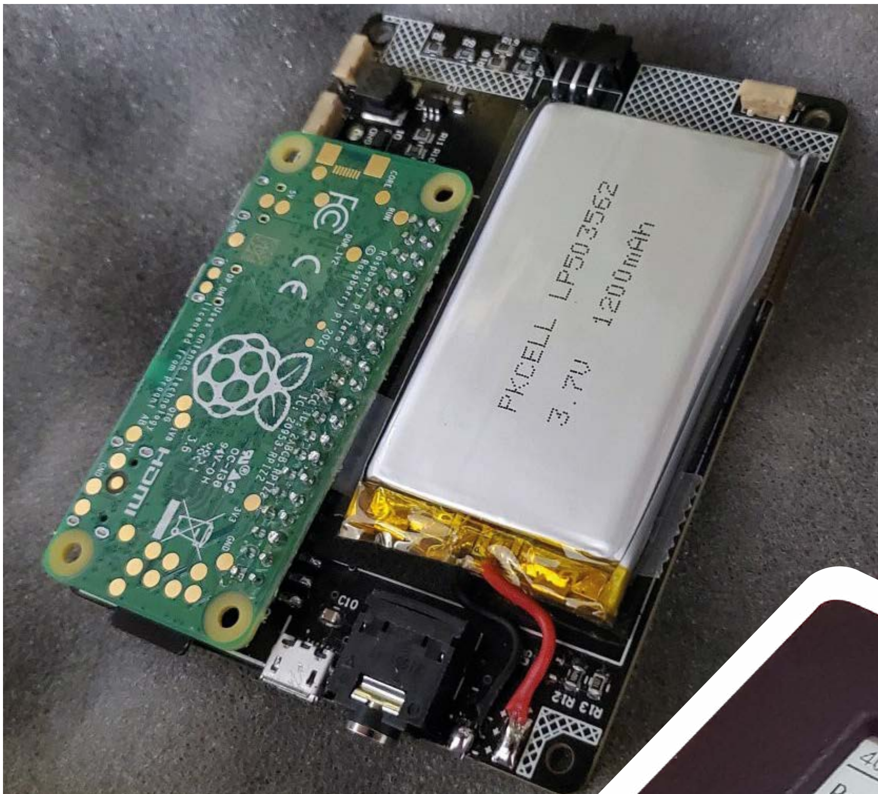
ePiPod

By **drhatch** hsmag.cc/EPiPod

The more things change, the more they stay the same, as the French say. We've seen the return of vinyl as an audiophile way of consuming music; now it looks like digital files are making a comeback over streaming services. At least, they are in one small corner of the internet. Inspired by maker Bram Rausch's PiPod, the ePiPod by drhatch takes a homegrown iPod-like music player, based on a Raspberry Pi Zero 2 W, and adds an e-paper screen, rather than the PiPod's 2.2-inch TFT screen.

The screen drhatch chose is a $6.99 display from Waveshare; the maker had to change the power supply from the original PiPod using Waveshare's reference design; the software also had to change, to incorporate the Waveshare driver library and the Pillow Python library. Apart from the lack of screen glare, e-paper has the advantage of lower power use than the original build.

There's no Apple-style scroll-wheel; instead, the ePiPod features five front-panel buttons for navigation and two side buttons for volume control. There's also an on-off switch. Unlike a streaming service, the ePiPod will work when there's no internet connection. It won't play ads, and it lets the user play albums from start to finish. Groundbreaking!



Left A Raspberry Pi Zero 2 W is a great way to add a lot of computing power without breaking the bank

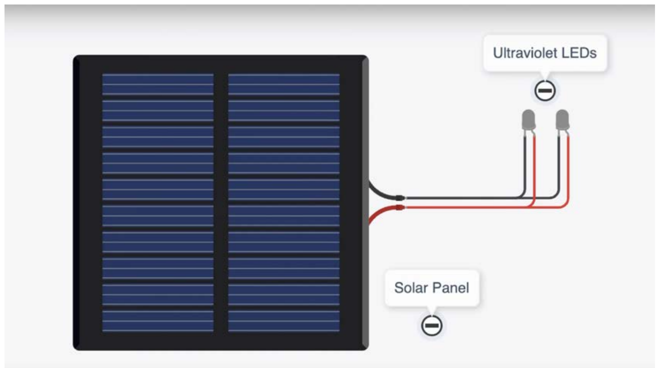
Solar water bottle

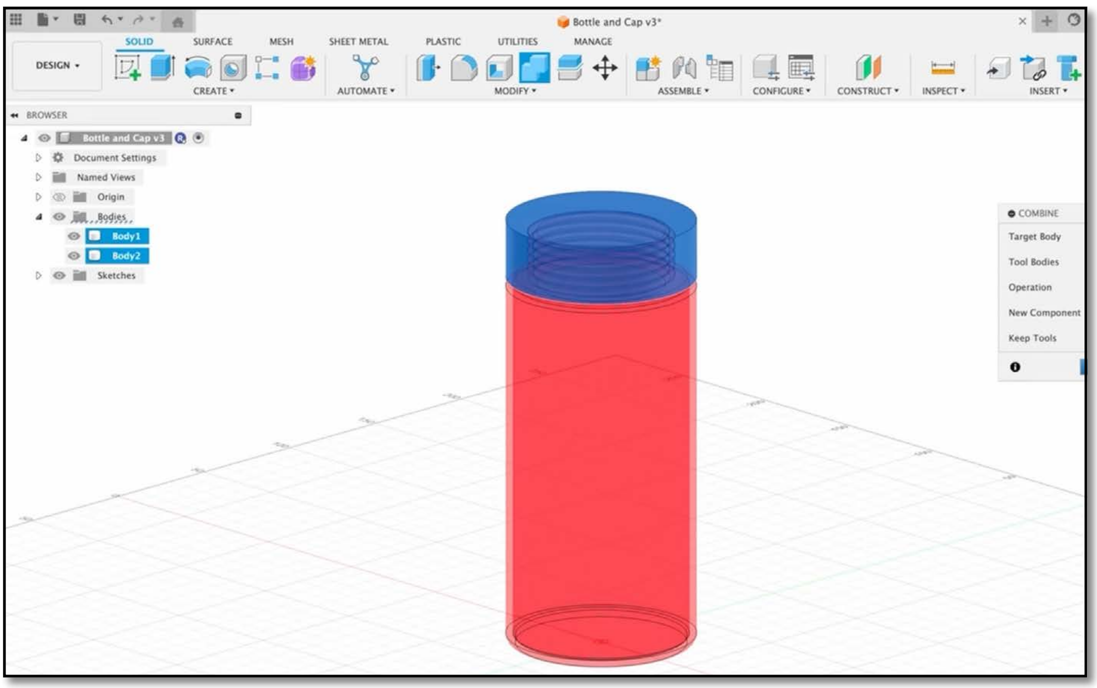
By **Aarav Garg & Riddhi Gupta**

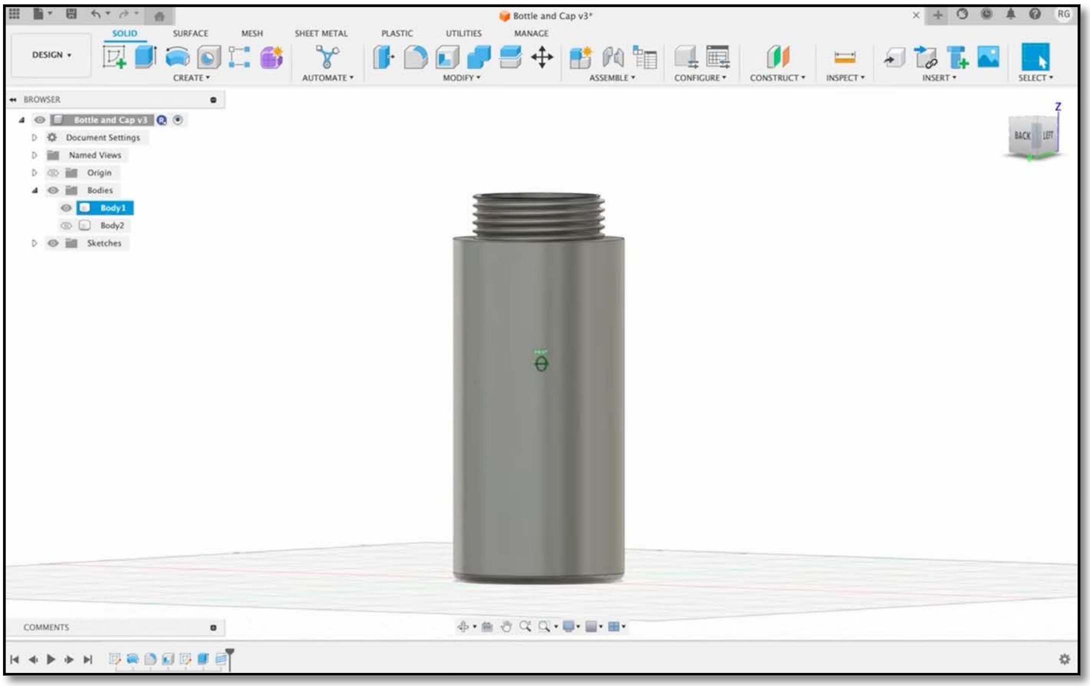
hsmag.cc/SolarWaterBottle

According to the World Health Organization, there are at least 1.7 billion people in the world today who drink water contaminated with faeces, putting them at risk of diseases including diarrhoea, cholera, dysentery, typhoid, and polio, with diarrhoea alone causing around a million deaths per year. If you live in a country where this isn't a problem, it means that the generations before you invested massive amounts of time and money into building sewers, wells, water treatment plants, reservoirs, and all the rest of the infrastructure that we should be grateful for every time we turn on the tap.

Where this infrastructure doesn't exist, there are other solutions. One of these is to treat water using UV light to kill harmful bacteria. This solar water bottle by Aarav Garg and Riddhi Gupta comprises a 3D-printed body with a circular 6V 80mA solar panel and two UV LEDs housed in the screw-on cap. We're fascinated by the simplicity of this project. We know that it's not massively scalable, but this is a fascinating approach to an eternal problem. □







Left Apparently, the optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm

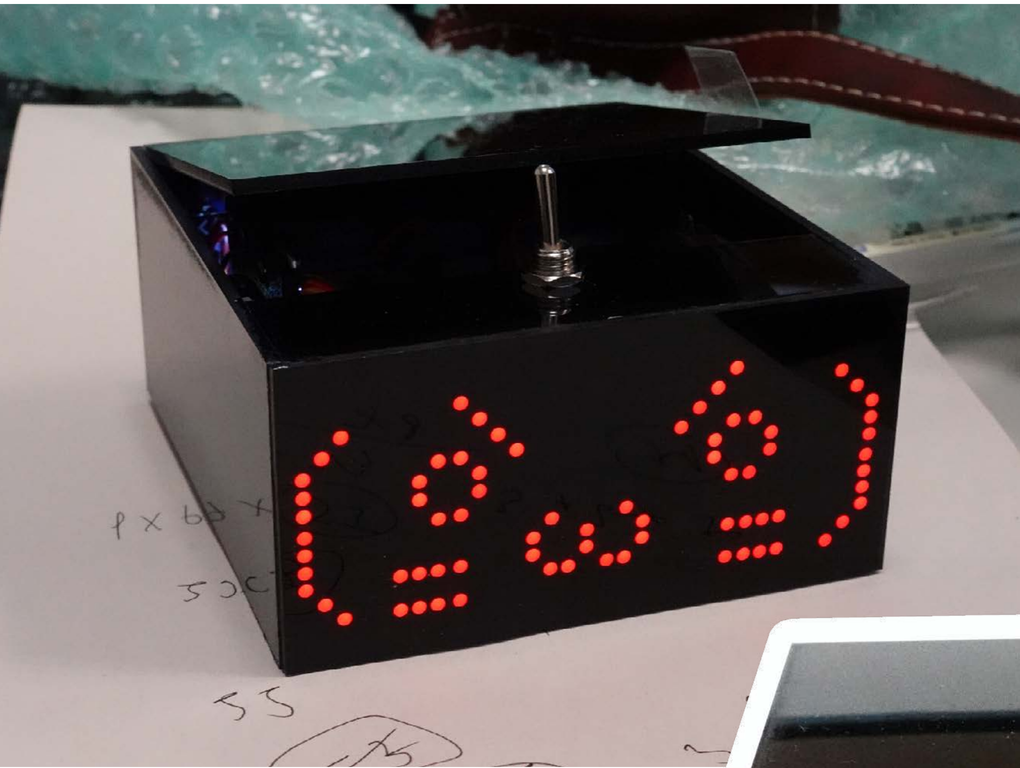
Useless Robot

By **Toby Chui** hsmag.cc/UselessRobot

Y ou've probably already seen some incarnation of the 'useless box' mechanism: it's a machine that turns itself off. More than that, it's a machine that mechanically, deliberately turns itself off: you flick a switch, then an arm appears from out of the box to flick the switch back and turn the machine off.

This version, by Toby Chui, has a couple of added features to the basic machine that turns itself off. First of all, there's that gorgeous little face, which is inspired by the Japanese 'Kawaii' aesthetic (Kawaii means 'cute'). Second, every time the user turns the machine on, the face gets a little more annoyed, until it's had enough, and the machine will run away.

If it were up to us we'd implement this with a Raspberry Pi Pico and perhaps some off-the-shelf motor drivers, but Toby has gone fully bespoke for this project, using an ESP32-based design and three custom PCBs. For that alone we applaud him, and when you add the cute factor and the beautiful build quality, this is one project that has really impressed us. □



Above
A lot of machines are useless; this one is useless by design

Vintage smart radio

By **Tsuryx** hsmag.cc/VintageSmartRadio

There are loads of upcycling projects that involve taking a cool old enclosure, ripping out the original electronics, and replacing them with a microcontroller – and don't get us wrong, we love that sort of thing. What makes this build different is that Tsuryx has kept all the original features of the Sony TFM-9450W radio, and added new ones without taking anything away.

The magic ingredient in this build is the audio signal mixer, an example of which is currently available on AliExpress for the princely sum of £1.19. This is what enabled the maker to retain the functionality of the radio – you simply unsolder the wires connecting the original radio to the speaker and route them via the mixer. Adding the Amazon Echo Dot requires some disassembly – you're removing most of the electronics from the smart device, including the speaker – but once that's done, there should be plenty of room inside the enclosure, and you should be able to connect the smart device to the audio signal mixer with a male-to-male 3.5 mm cable.

There's obviously more to the build sequence, but if we're honest, there's not a lot more, which makes this a perfect project for anyone who wants to dip a toe into modifying old hardware.

Left The nature of this build means that there's not a great deal to see – all the magic is on the inside

LENS

HACK | MAKE | BUILD | CREATE

Uncover the technology that's powering the future

PG 30

HOW I MADE: **MIDI PIANO**

Fill your house with beautiful sound without spending years learning how to tinkle the ivories

PG 36

INTERVIEW: **TOBY ROBERTS**

A maker ensconced in Raspberry Pi HQ reveals how he's using the single-board computer

PG 18

50 ELECTRONICS PROJECTS

Dozens of ways to improve your making

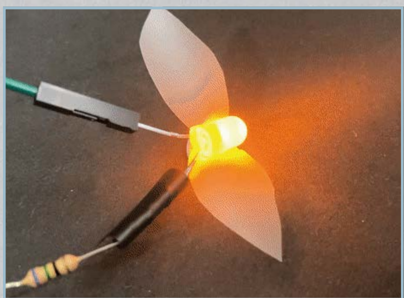
50 ELECTRONICS PROJECTS

With a microcontroller and a few other components, you can make a vast array of electronics projects…

By **Phil King**

LED

When building your first electronics circuit on a breadboard, the easiest output device to use is a standard single-colour LED (light-emitting diode). As with other diodes, current only flows in one direction, so you need to get the polarity right: connect the positive (long) leg to an I/O pin on your microcontroller, and the negative (short) leg to ground. Remember to add a resistor to either connection to limit the amount of current to a safe level.

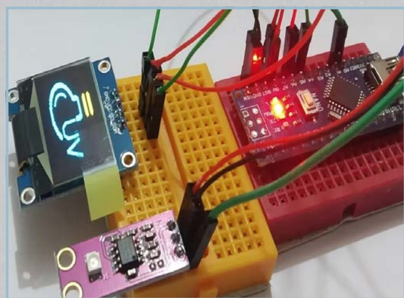


LED Firefly
A variation on the classic blinking LED starter project, here a yellow LED is given sticky-tape wings and turned on and off by switching a Raspberry Pi Pico I/O pin high and low

hsmag.cc/LEDFirefly

UV SENSOR

This special type of light sensor can detect the level of ambient ultraviolet (UV) light, outputting a relative voltage (or digital data in some sensors). From that output, it's possible to determine the international standard UV index level, so you know how safe it is to go out in the sun and whether to apply sunscreen. Naturally, the sensor needs to be placed outdoors to work effectively.

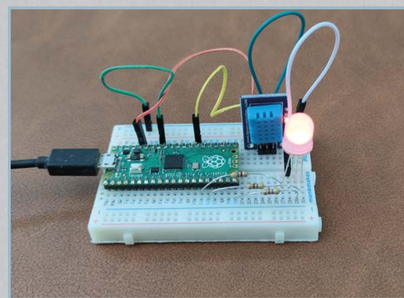


UV Index Meter
This Arduino project makes use of a GUVA-S12SD ultraviolet sensor and shows the UV index on a mini display

hsmag.cc/UVIndexMeter

RGB LED

A standard RGB LED is essentially three LEDs in one, with red, green, and blue components. It therefore has four pins: three for the red, green, and blue channels (connected to I/O pins via resistors) and one for either GND or 3V3 (check which type you have). By using PWM (pulse-width modulation) to vary the brightness level of each colour channel, you can get it to show any of the 16 million shades.

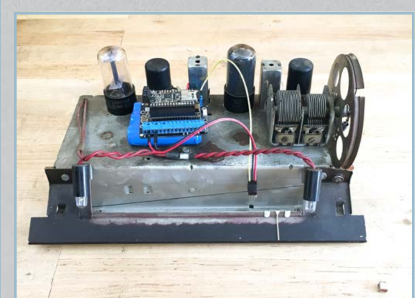


RGB Lamp
In our example tutorial (see page 50), a common-cathode RGB LED is connected to the GPIO pins of a Pico. Varying the PWM frequencies on each channel will alter its colour (here determined by the data from a temperature sensor)

hsmag.cc/PicoRGBLED

HALL EFFECT SENSOR

Named after the American physicist Edwin Hall, this type of sensor detects changes in a magnetic field: its output voltage is directly proportional to the strength of the field. This enables it to detect the position and movement of magnetic objects. Hall effect sensors have many uses, such as in the automotive industry, to determine a car's fuel tank level and the speed of its wheels.

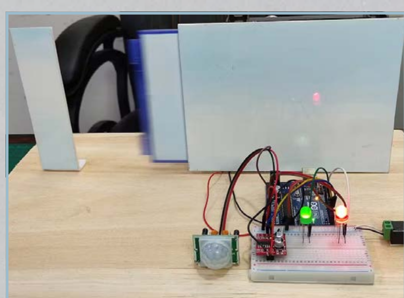


Haunted Radio
A Hall effect sensor detects the presence of a magnet as you turn the dial, triggering the playback of spooky sounds

hsmag.cc/HauntedRadio

PIR MOTION SENSOR

A PIR (passive infrared) sensor, such as the HC-SR501, can detect movement even in a darkened room, making it ideal for burglar alarms. It detects changes in the area covered by its plastic lens, and outputs a digital signal when it detects movement. The sensitivity threshold and trigger time can be adjusted (typically by turning a couple of screws).



Automatic Door Opening System
Here, a PIR sensor is used to detect the movement of anything approaching, triggering a sliding door to open. You could scale the concept up to life-size

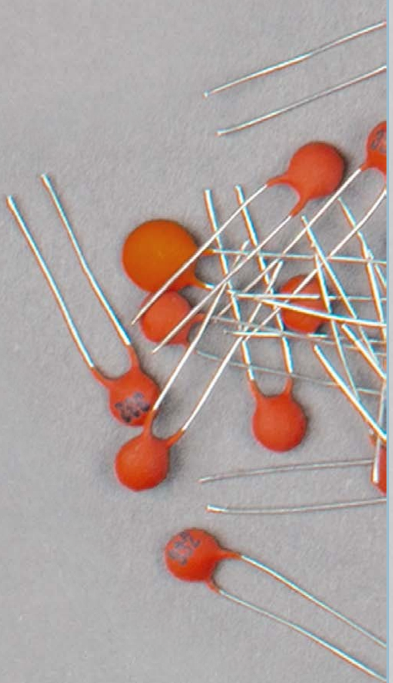
hsmag.cc/PIRDoor

CHARLIEPLEXING

An alternative to using NeoPixels for a display is to multiplex a set of standard LEDs. This involves connecting them in a matrix of addressable rows and columns, thereby reducing the number of GPIO pins needed to control them. A particular type of multiplexing is called charlieplexing, which allows you to drive N×(N-1) LEDs with just N pins, making it easy to add multiple standard LEDs to a project.

Atom Watch
This wristwatch shows the time in analogue form via two concentric circles of 42 LEDs, for hours and minutes. Charlieplexing is used to drive them all from ten pins on an Arduino Pro Mini

hsmag.cc/AtomWatch



MOISTURE SENSOR

Ideal for monitoring the soil in a pot plant or garden, this kind of sensor is a type of variable resistor with two prongs; one emits an electrical current that is received by the other via the soil (or other medium). The more moisture there is in the soil, the higher the conductivity and thus the greater the current delivered. Some more expensive models have multiple sensor elements at different depths.

Plant Waterer
A capacitive soil moisture sensor is used with a Pico microcontroller to trigger a relay switch to turn on a fish tank water pump

hsmag.cc/PicoPlantWaterer

FLIGHT CONTROLLER

A next-level project is to build your own aerial drone such as a quadcopter. For this, you'll need a flight controller, either in the form of an all-in-one unit or separate ESC (electronic speed controller) and IMU. Using telemetry data from the IMU, with optional GPS, it adjusts the speed of the propeller motors to keep the drone stable in the air. Another use case for a flight controller is in rocketry, to control a rocket's trajectory and reach the desired altitude.

RC-VTOL-F35-ParkJet
Nick Rehm's highly manoeuvrable aircraft features separate ESC and IMU units for fine control of its propellers and ailerons

hsmag.cc/F35ParkJet

NEOPIXEL

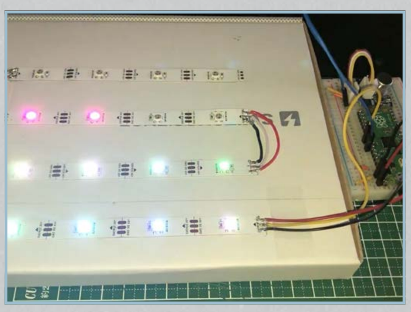
If you want to connect several standard RGB LEDs, you'll soon run out of GPIO pins. That's where smart, individually addressable RGB LEDs come in really useful, enabling you to send a digital number over a single connection to determine the shade. The most popular type is the WS2812B standard, aka NeoPixels, available as individual pixels or more often in sticks, reels, shapes, and matrices. With an integrated driver chip mounted on every LED, only three connections (power, ground, and data) are needed to control as many as you like (so long as enough current is supplied).

Crystal RGB
This simple Arduino-compatible project places a single WS2812B LED inside a 3D-printed crystal to make it glow in different colours, making it ideal as a desk ornament

hsmag.cc/CrystalRGB

SOUND SENSOR

Equipped with a tiny amplifier, a low-cost sound sensor will trigger a digital output signal whenever a certain ambient noise threshold is reached. This makes it useful as part of an intruder alarm. Most such sensors also have an analogue pin which outputs the sound itself. Sensitivity and noise threshold for the sensor are typically adjusted with small potentiometer screws.

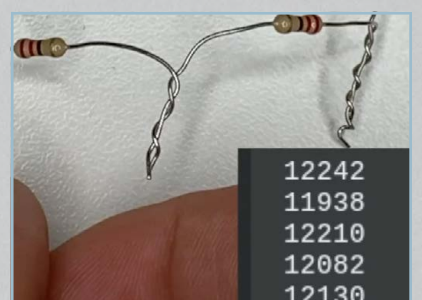


Sound-Activated RGB LED Matrix
Using a sound sensor, colourful patterns are triggered on an RGB LED matrix in reaction to music or any sound

hsmag.cc/SoundMatrix

RESISTOR

Resistors limit the amount of current flowing through a circuit, making them especially useful to prevent LEDs burning out due to overcurrent. Resistors can also be used to create a 'voltage divider', to reduce an input voltage; this is typically used to connect the output of a 5V component (such as an HC-SR04 ultrasonic sensor) to a 3V3 input. Through-hole resistors have coloured bands that represent their power rating, in ohms – see **hsmag.cc/ResistorCalc**.



Resistor Piano
By stringing a series of resistors together, the resistance at each junction is different, enabling it to be used to trigger a particular musical note in this Pico project

hsmag.cc/ResistorPiano

WEATHER STATION

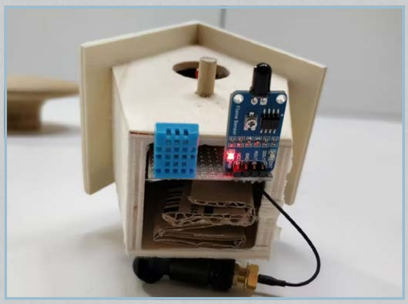
When building a weather station, in addition to including one or more sensors for temperature, pressure, and humidity, you'll want to take other meteorological measurements. A rotating anemometer measures wind speed, while a vane detects wind direction. A rain gauge is another essential item; there are two main types: the simplest uses a rocker switch, while the alternative relies on an infrared beam.

Precise Anemometer
When an anemometer spins in the wind, the number of turns per second indicates the wind speed. This project has a linear LED scale to show it

hsmag.cc/PreciseAnemometer

FLAME SENSOR

As the name suggests, this type of sensor can detect the presence of a nearby flame. While many commercial sensors use ultraviolet technology, low-cost hobbyist flame sensors rely on PIR to detect the infrared energy emitted by a fire. The sensitivity, and therefore the range, may be adjusted using an on-board potentiometer screw. Along with an analogue output, some may have a digital one.

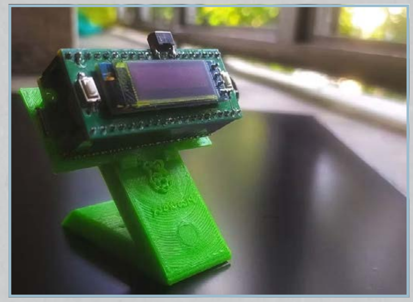


Forest Fire Detector
Housed in a birdbox-style enclosure, this Arduino-based fire detector features an IR flame sensor and uses the Sigfox communications platform to transmit alerts

hsmag.cc/SigFoxFire

REAL-TIME CLOCK

If you want your microcontroller project to keep track of time when it's powered down, you'll need a real-time clock (RTC) module. Powered by a backup battery, usually a coin cell, this type of integrated circuit will supply the correct time when the project is powered back on. It's ideal for use in DIY alarm clocks, calendars, or anything that requires a timer.

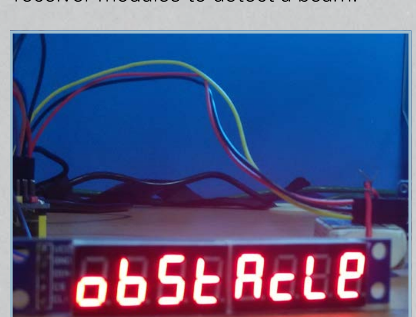


PicoClock
This multifunctional mini clock features a high-accuracy RTC module to keep the right time. A Li-ion battery is used to power the RTC

hsmag.cc/RTCPicoClock

LASER SENSOR

Another useful element of an intruder alarm system is a laser sensor. It may not resemble the impressive laser security systems seen in *Mission Impossible* films, but it works in the same way. A laser beam of a set wavelength is emitted via an on-board lens; when reflected by a wall, or other solid object, it is sensed by a receiver. Thus it can detect when the beam is broken, triggering a digital output. Alternatively, you can use separate laser modules and receiver modules to detect a beam.



Obstacle Detector
Laser sensors are also useful for obstacle detection, as demonstrated here. They can also be integrated into a wheeled robot for this purpose

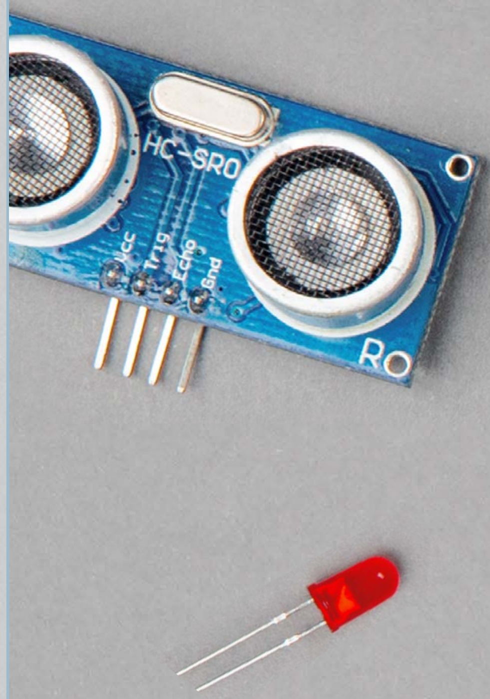
hsmag.cc/LaserObstacle

MOTOR

If you want something in your project to move, you'll need one or more DC motors (along with a motor driver). They come in different sizes and types, such as brushed or brushless. Micro metal gear-motors feature a built-in gearbox that can alter the output rpm (i.e. speed) and torque. The higher the gear ratio, the higher the output torque, but lower the top speed. While standard continuous rotation motors are ideal for wheeled robots, servos or stepper motors are far better when precision movement is required.

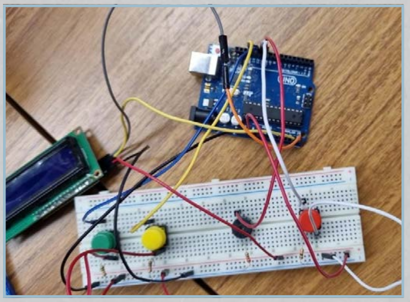
Bubble Machine
An H-bridge is used to drive two DC motors: one in a fan that spins to make the bubbles; the other to turn a wheel with holes in it for bubbles to pass through

hsmag.cc/BubbleMachine



SWITCH

One of the most common input devices in electronics projects is the momentary switch. The most common type only outputs a signal when kept pressed. Another type is the latch switch, which stays on/off after being pressed. They come with two or four legs, only two of which need to be connected to an I/O pin and ground.

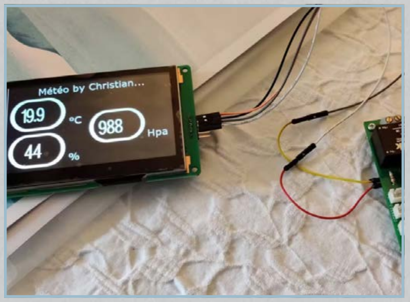


Morse Code Converter
Using three push-buttons, this Arduino project lets you translate the dots and dashes of Morse code into text on a mini display

hsmag.cc/MorseConverter

PRESSURE SENSOR

This type of sensor measures the barometric pressure of the atmosphere, which in turn can be used to calculate the altitude. Some sensors can measure both temperature and pressure (e.g. BMP280) – and some add humidity too, such as the popular BME280. Another type of sensor can measure the pressure of a liquid.

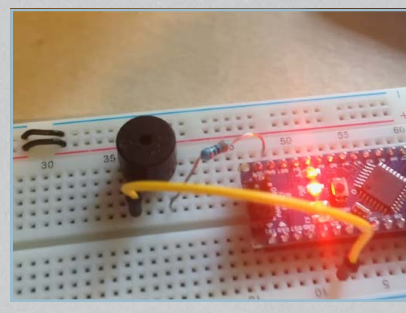


Touchscreen Barometer
Making use of a BME280 sensor, to measure pressure along with temperature and humidity, this Arduino barometer project outputs the data on a mini touchscreen

hsmag.cc/ArduinoBarometer

PIEZO BUZZER

Another type of output device, a piezoelectric buzzer can emit simple buzzing sounds. By varying the PWM signal to it from your microcontroller, it's even possible to change the pitch to create rudimentary music. There are two main types of buzzer: active and passive. Active buzzers are far easier to use, as they generate their own oscillations for the buzz.

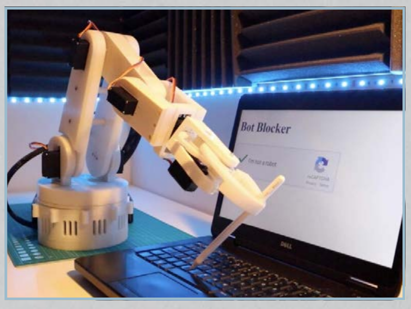


Musical Buzzer
By varying the PWM signal, you can get a piezo buzzer to make music, such as the Super Mario theme. You just need to know the required frequency for each note

hsmag.cc/MusicalBuzzer

ROBOTIC ARM

Often used in industry, robotic arms are able to manipulate objects and perform repetitive tasks, such as 'pick and place'. Hobbyist kits range from lightweight arms to more robust heavy-duty ones – with a very wide price range. The number of degrees of freedom (DOF) indicates how many servo-powered joints they have. Check out the power and accuracy ratings too.



MARK1
Comprising 3D-printed parts, this Arduino arm has 6DOF and can mimic the hand gestures of the wearer of a glove fitted with sensors

hsmag.cc/ArduinoArm

BIPOLAR JUNCTION TRANSISTOR

The invention of the transistor eliminated the need for vacuum-tube valves for electrical signal switching and amplification. Bipolar junction transistors (BJTs) come in two main types: NPN and PNP, for use in the negative and positive side of a circuit, respectively. A base terminal is used to control the current flowing between the collector and emitter terminals.

RGB Infinity Mirror
Comprising two BJTs, Darlington transistors (aka pairs) are used to amplify current. In this project, they're used to drive a long RGB LED strip

hsmag.cc/RGBInfinityMirror

CUSTOM PCB

Using a breadboard or perfboard is fine for prototyping projects, but for a better end product you'll want to create a custom PCB. Designing one is not as daunting as you might think, using free software such as EasyEDA, and you can get it manufactured by a supplier at fairly low cost. Check out the beginner's guide we brought you in HackSpace issue 48 (**hsmag.cc/issue48**).

Reflow Oven PCB
This custom PCB was created to drive a reflow oven for the soldering of surface-mount electronic components to PCBs

hsmag.cc/ReflowOvenPCB

MOSFET

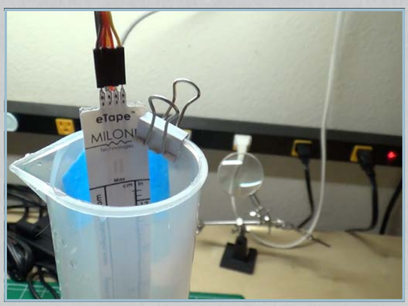
A MOSFET (metal oxide semiconductor field-effect transistor) controls the flow of electricity between its source and drain terminals depending on the voltage applied to its gate terminal. This makes it useful for switching or amplifying high-power DC electronic signals. In particular, it can switch them on and off more quickly than a relay can.

Pico DC Fan Driver
To drive the DC motor load for the fan, a high-power AO4406 N-channel MOSFET is used for fast switching purposes

hsmag.cc/PicoFanDriver

LEVEL SENSOR

This type of sensor is ideal for measuring the level of a liquid, such as in a water tank. The most common low-cost version measures the conductance between metal strips or prongs, similar to the method used by a soil moisture sensor. As the water gets higher, the conductivity level increases across the strips, boosting the signal sent from an analogue output.

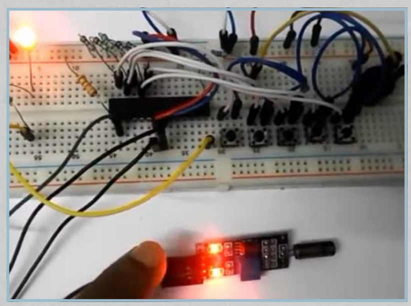


Smart Measuring Cup
The eTape liquid level sensor here alters its resistance output according to the level of the water in the cup, with the volume displayed on a web page

hsmag.cc/MeasuringCup

TILT SWITCH

Old-fashioned tilt switches used mercury, which is highly toxic, so it's best to avoid those. These days, a non-toxic substance is used to conduct electricity between the two contacts of a switch. This only happens when the switch is tilted beyond a certain angle. An alternative type uses a tiny ball in a cage to connect the contacts at an angle.

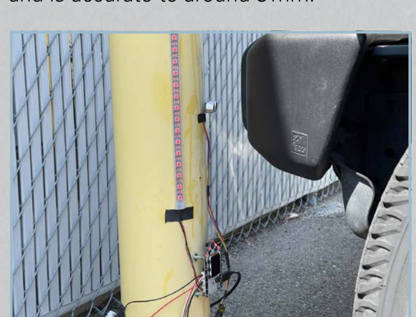


Anti-Theft Alert System
A ball-and-cage tilt switch is used for this demonstration of a simple anti-theft alert system, triggering an LED and buzzer alarm when moved

hsmag.cc/TiltAlarm

ULTRASONIC DISTANCE SENSOR

Using a form of sonar, this type of sensor emits ultrasonic pulses and then listens for the echoes; the time delay is used to calculate the distance to a nearby object. This makes it ideal for an obstacle avoidance system in a wheeled robot, which can detect walls or other obstacles and take evasive action. The popular HC-SR04 sensor has a range of 2–400 cm and is accurate to around 3 mm.



Parking Aid
Ultrasonic distance sensors are fitted on the rear of many cars to aid parking. This garage parking aid operates in a similar way, using an HC-SR04 sensor on the wall

hsmag.cc/ParkingAid

POTENTIOMETER

A potentiometer, or 'pot' for short, is a type of variable resistor. There are two main types: rotary (with a knob) and linear (slider). As you turn the knob (or move the slider along), the level of resistance is altered, affecting the voltage output from an analogue pin. While pots have many uses, the most common is as a control method, such as for audio volume on a sound system.

Bike Stereo System
In this fun project to add a 20 W sound system to a push-bike, a potentiometer is used to adjust the volume of the music

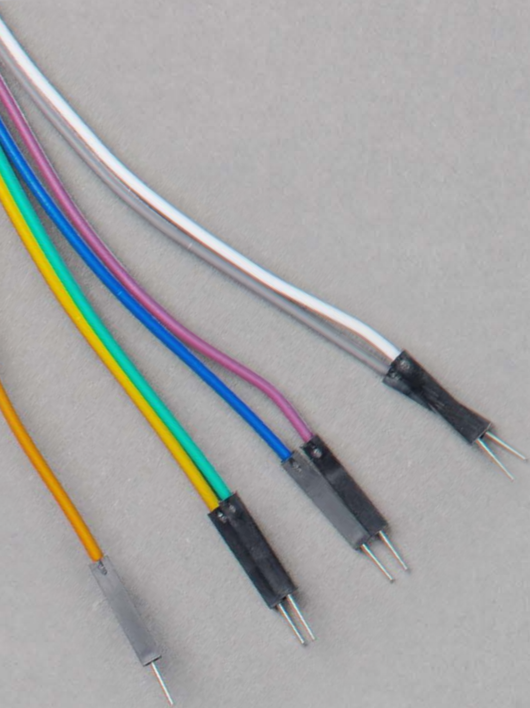
hsmag.cc/BikeStereo

GAS SENSOR

There are several low-cost gas sensors available, each able to detect different toxic gases in the air. For instance, the MQ5 sensor can detect the presence of LPG, natural gas, and coal gas, so is ideal for making a gas leak alarm. The MQ9 can also detect carbon monoxide. While most such sensors have an analogue signal output, some also have a digital one.

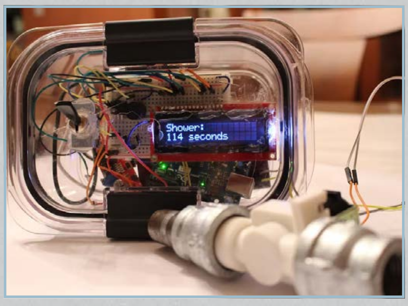
Gas Analyser
This Arduino-based analyser packs three different gas sensors (MQ4, MQ5, and MQ135), along with a DHT11 for temperature and humidity monitoring

hsmag.cc/GasAnalyser



SOLENOID

A solenoid is an electromagnet in which the core can move back and forth, making it useful as a switching mechanism. Solenoids often have a spring to return the core to a rest position when the voltage is turned off. Note that since solenoids require more power than a microcontroller can supply, you'll need a driver board or circuit to use them.



Shower Regulator

A solenoid can be fitted in a valve to control the flow of water, such as in this Arduino project that limits your time in the shower before shutting off the water

hsmag.cc/ShowerRegulator

MINI DISPLAY

If you want to show a readout of data without connecting your microcontroller to a computer, you'll need a mini display. They come in a range of sizes and types, such as standard LCD (liquid crystal display), TFT (thin-film-transistor LCD, and OLED (organic light-emitting diode). Or there's the classic seven-segment LED type. Another option is an e-ink/e-paper screen, which only uses power when updating.

PiConsole

Mini colour displays are ideal for use in portable video game systems such as this Pico-powered retro console, which features a 1.54-inch OLED

hsmag.cc/PiConsole

RFID AND NFC

Radio-frequency identification (RFID) is a contactless technology that enables devices to send data without a wired connection. NFC (near-field communication) is a subset of RFID that permits two-way data exchange at short range (a few centimetres). Passive RFID and NFC tags require no independent power source, as they're powered by the receiving device's radio waves. Uses include for door entry systems, pet feeders, and triggering home automations.

Paper Man

An Arduino NFC shield is used here to transfer messages from a phone to the 'paper man', who then spits them out via a thermal printer in his mouth

hsmag.cc/PaperMan

SIGNAL FILTERING AND AMPLIFICATION

With the use of capacitors along with resistors or inductors, an electronic signal (such as that generated by an oscillator circuit) can be filtered, enabling only certain frequencies to pass through, thus reducing unwanted signal noise. Signals can also be boosted with a transistor-based amplifier circuit. These concepts are used in IC-based op-amps, sophisticated differential amplifiers with high gain.

Metal Detector

In this simple metal detector, a Colpitts oscillator comprising an inductor and two capacitors produces stable sinusoidal oscillations for the electromagnet field to detect metal objects

hsmag.cc/MetalDetector

REED SWITCH

These magnetically operated switches typically feature two thin, flexible 'reeds' – metal wires or blades – with a small gap between them in a sealed glass bubble. When a magnetic field is applied, it pushes the reeds together so they make contact. That's in the most common, normally open (NO) variety – in a normally closed (NC) switch, the reeds are pulled apart. There's also the changeover type, in which a reed is moved to switch contact between two other reeds.

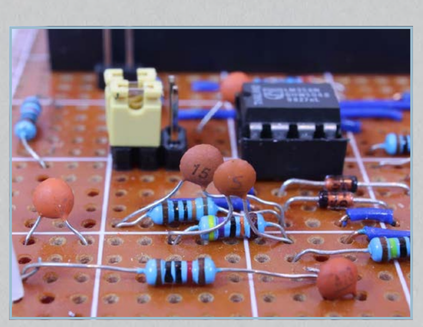
Bike Speedometer

A reed switch (on the wheel spokes) and magnet (on the bike frame) are used to count the wheel rotations and calculate the bike's speed

hsmag.cc/BikeSpeedo

CAPACITOR

Found in most electrical devices, capacitors are able to store electrical charge, similar to a battery but able to discharge far more quickly. Uses include power regulation and signal filtering. They come in a variety of values, shapes, sizes, and materials. A capacitor's 'breakdown voltage' is the highest it can accept before breaking down, so make sure not to exceed that.



Stripboard Oscilloscope MkII
The performance of this Pico-based oscilloscope was improved by simply adding two capacitors in the feedback path of the LM358 op-amp

hsmag.cc/PicoOscilloscope

CONDUCTIVE MATERIALS

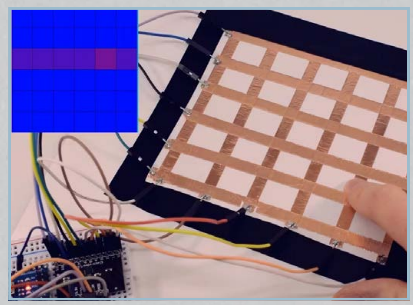
You don't have to use jumper wires to connect components in a prototype circuit. Alternatives include conductive thread, ideal for wearables, and conductive ink. Used with a rollerball pen, the latter enables you to scribble a working circuit design on a piece of paper – great for learning. Or you can use pieces of copper tape to create a circuit. There's also conductive paint, although that may be more useful for creating capacitive touch inputs.

Sparkle Skirt
Conductive thread is great for connecting components in wearable projects such as this light-up sparkle skirt controlled by an Adafruit FLORA microcontroller

hsmag.cc/SparkleSkirt

TOUCH INPUT

As well as for screens, capacitive touch can be used for touch-activated switches. While you can buy capacitive touch pad breakouts, you don't need one to try out the concept. Simply connect a high-rated (e.g. 1 megohm) pull-down resistor between a microcontroller ground pin and I/O pin, with a jumper wire coming from the latter to act as a touch input. Or you can connect the wire to any conductive item, such as a piece of aluminium foil or even a piece of fruit.



Sensing Grid
This Arduino project uses a capacitive touch sensor breakout to turn a grid of copper tape strips on some paper into a multi-touch input device

hsmag.cc/SensingGrid

ROTARY ENCODER

Unlike the similar-looking rotary potentiometer, an encoder generates digital (not analogue) signals as you turn the knob. There are two main types of encoder: absolute (which detects the position set) and incremental (which only senses movement in either direction). So make sure you pick the right one for your project. Encoders typically double as a push-button when you press them in. There is also no limit to the number of rotations that can be made, unlike a pot.

HotKeys v2
Rotary encoders are often included in mechanical keyboards, for the scrolling of pages etc. This one is in a programmable macro keypad

hsmag.cc/HotKeys

DIODE

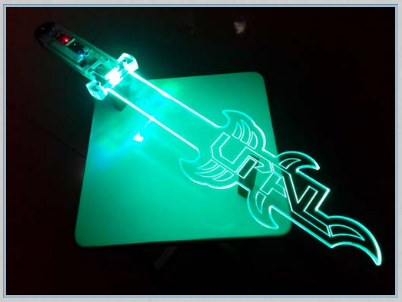
While an LED is a specialised type of diode, the key property of diodes in general is that they allow electrical current to only flow in one direction. In addition to standard diodes, Zener and Schottky diodes have special characteristics. Common diode uses include power rectification (including converting AC current to DC), back EMF protection to prevent very high voltages, power gates to switch between two sources, and clamps to limit voltage.

Flame Painting
Diodes are useful for regulating the power supply to NeoPixels, such as in this illuminated artwork, to avoid damaging spikes

hsmag.cc/FlamePainting

COLOUR SENSOR

As the name suggests, this type of optical sensor (such as the TCS230 or TCS3200) can detect a variety of colours. Some of its multiple photodiodes are equipped with different coloured filters (typically red, green, and blue), enabling it to calculate the shade of a nearby surface illuminated by a bright white LED.



Light Painting Sword
This smart light-up sword has a colour sensor on the hilt that picks up the shade of the wielder's clothes so the RGB LED colour can be matched

hsmag.cc/LightSword

LIGHT SENSOR

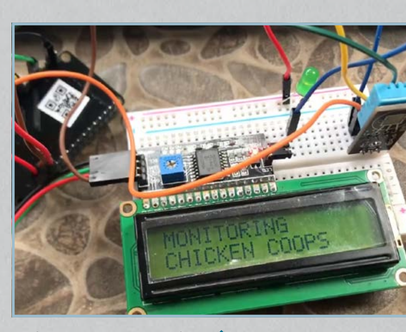
The most basic form of light sensor is an LDR (light-dependent resistor), whose output voltage alters according to the light level falling on its surface. It's not very accurate, but fine for detecting changes in the light level, making it usable in an intruder alarm. Other, more sophisticated light sensors, such as the LTR-559, give accurate digital readings.

Optical Glove Controller
This glove controller has a flexible tube that has an LDR and LED at either end – when flexed, the drop in the light level is sensed

hsmag.cc/OpticalGlove

TEMPERATURE SENSOR

There are many types of temperature sensor, some of them housed in a metal probe on a wire that can be placed in a medium such as soil. A couple of the most common types are the low-cost DHT11 and DHT22, which also measure relative humidity and give a digital output. They're a little basic, but fine for most hobbyist projects.



Chicken Coop Monitor
Here, a DHT11 temperature sensor wired to an ESP32 microcontroller is used to monitor the conditions in a chicken coop to help ensure the birds' well-being

hsmag.cc/ChickenCoopTemp

BUCK CONVERTER

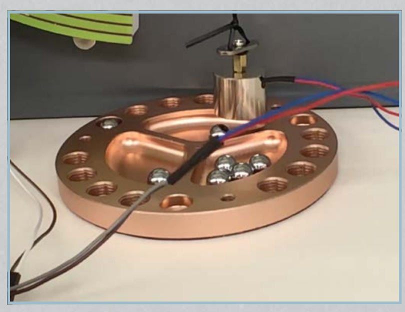
When powering multiple parts of a project from a single source, you may well need to reduce the voltage for your microcontroller or other components. A buck (aka step-down) converter will do this, while also helping to regulate the power supply and eliminate voltage spikes. You can also boost a battery's voltage, if needed, using a step-up converter. For more info, see the 'Don't forget the batteries' tutorial in HackSpace issue 76 (**hsmag.cc/issue76**).

Dog Ball Launcher
This 3D-printed dog ball launcher needs power for two 12V motors, but just 3.3V for the Pico microcontroller, for which it uses a DC buck converter

hsmag.cc/DogBallLauncher

INDUCTOR / ELECTROMAGNET

At its most basic, an inductor is a coil of wire; when you apply a voltage to it, a magnetic field is generated and grows stronger. When the field eventually collapses, the stored electricity is released. Therefore, inductors are useful for storing and delivering energy, as well as for slowing current surges and spikes. Wrap the coil round a metal core and you can create an electromagnet, which is only magnetic when power is applied.



Mag-Neat-o
An electromagnet can be turned on and off to pick up and drop metal objects such as ball bearings, as in this project

hsmag.cc/MagNeato

RELAY

A relay is an electromechanical switch that can be closed or opened by applying a control signal. It is especially useful when you need to switch higher voltage or currents than your microcontroller can handle – make sure to note the relay's maximum load, however. While some relays can handle mains AC voltage, you shouldn't attempt this unless you really know what you're doing – even then, make sure to use an RCD.

Hands-Free Garage Door
Equipped with a high-power relay shield, a Particle Spark Core microcontroller board is able to drive a motorised garage door opener

hsmag.cc/GarageDoor

SERVO

A servo is a special type of DC motor that (in most cases) only moves within a limited range, typically 180 degrees. The upside is that, with a built-in potentiometer, the angle can be set by a PWM control signal. This enables any component attached to the servo's 'horn' to be moved to the desired position. Among other uses, servos feature commonly in robotic arms, legs, and grippers.

Robotic Hand
This 3D-printed hand features five servos, each of which pulls a thin wire to move a finger to match the movements of a glove with flex sensors

hsmag.cc/RoboticHand

LIQUID PUMP

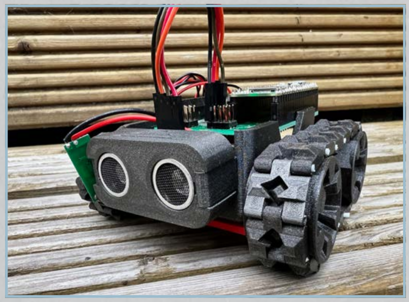
The ability to control the pumping of a liquid through a tube is useful in projects such as a plant waterer or drinks dispenser. The most common type of pump used in hobbyist electronics is the peristaltic pump. Using a high-torque DC motor to alternately squeeze and relax a flexible silicone tube, it never comes into contact with the liquid.

Cocktail Machine
The makers of this Arduino-based drinks dispenser opted to use air pumps, rather than peristaltic ones, for faster pouring

hsmag.cc/DIYCocktail

WHEELED ROBOT

The most popular type of hobbyist robotics involves the building of wheeled vehicles. There are countless kits available, as well as a vast array of chassis and components for building custom robots. You'll need one or more H-bridge motor drivers to enable you to power wheels and spin them forwards and in reverse. For a self-driving robot, you'll also need to include sensors and/or a camera to aid obstacle avoidance.

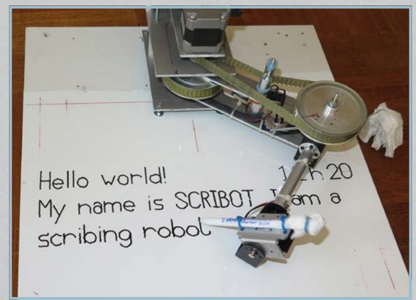


PicoSMARS 2
Based on the Screwless Modular Assemblable Robotic System (SMARS), this 3D-printed robot is controlled by a Pico W and has tank tracks

hsmag.cc/PicoSMARS2

STEPPER MOTOR

An alternative to a servo motor, this is a type of brushless DC motor that divides a full 360° rotation into a number of steps – determined by the step angle. Unlike a servo, it does not require a feedback mechanism for a microcontroller to read its position, since it can be commanded to move a set number of steps. Stepper motors are commonly used in 3D printer mechanisms and CNC machines.



Scribot
This scribing robot arm is equipped with stepper motors for precision movement as it faithfully reproduces vector letters to write messages

hsmag.cc/Scribot

IMU

An inertial measurement unit (IMU) enables you to sense how a device or vehicle is moving and oriented. It usually comprises an accelerometer, gyroscope, and magnetometer. IMUs are used in commercial products such as smartphones, fitness trackers, and some game controllers. For DIY projects, they're most often seen in robots or drones, aiding balance and navigation.

Balancing Robot
Based on an ESP-01 microcontroller with a 6DOF IMU, this simple robot is able to balance on two wheels using a double-stage PID controller

hsmag.cc/BalancingRobot

WALKING ROBOT

A more advanced robotics project is to build a walking robot with servo-powered joints. The more legs it has, the easier it is for it to stay upright, such as in spider- or insect-like robots. An IMU is highly recommended to help a bipedal bot maintain its balance. Creating a custom humanoid robot from scratch isn't easy, so it's better to try building a kit first.

Biped Robot
While many legged robots use servos in their joints, a far simpler method is to use a DC motor and cogs to create a walking motion, as in this LEGO robot

hsmag.cc/BipedRobot

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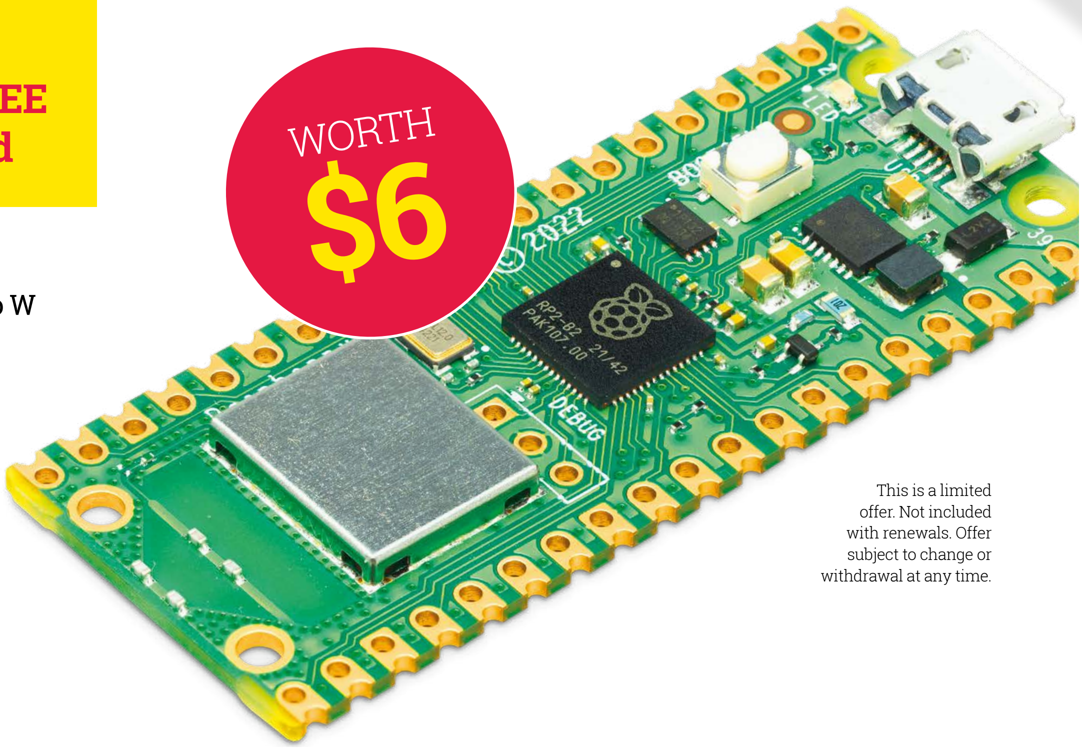

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HOW I MADE

MIDI PLAYER PIANO

By **DR. ROSS HAMILTON** with **ROB MILES**

It turns out that you don't actually decide to create a digitally controlled piano containing 88 solenoids, a bunch of controllers, a beefy power supply, and an awful lot of wires. You just kind of end up with one. I really like the sound of a live, well played, piano. So, I thought, why not learn to play one? I was lucky enough to have a piano at home, and so I loaded up a piano teaching app and got started. The app listened to the 'music' that I was making, and told me if I was playing it right and making progress as a pianist.

And then the problems began. It turned out that piano teaching apps are not good at recognising what they hear once the music gets complicated. Pieces I played perfectly apparently contained bum notes, and I could easily defeat the app and get a perfect score by bashing lots of keys at once. This is not a criticism of the app: recognising individual notes in a bunch of simultaneously played ones is fiendishly difficult, and doing it consistently is hard too. And it does, mostly, work. However, an accuracy of 99% still means that one note in 100 was not recognised correctly, making practice more work than it should be. So, the next step was to find an electronic piano with a MIDI (Musical Instrument Digital Interface) connection that could send note information directly to my tablet. So, I started searching for a suitable instrument.

Figure 1 The brand name probably reflects the fact that many pianolas were used in churches to provide music for hymn singing

Figure 2 Some rolls are also printed with music lyrics and sound effect instructions

Figure 3 The coins were added to the keys to give them weight and make them move down when their note is being played

PLAYER PIANO

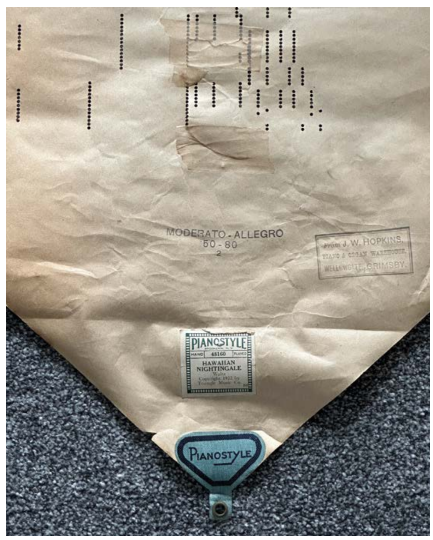
It turns out that when you search for 'digital pianos' in an online marketplace, you also get bombarded with listings for other things, including mechanical player pianos or 'pianolas'. These are awesome machines I'd not seen much of before. They are like a piano, but heavier (as if you thought that was possible) because they contain a lot of extra machinery. They have been around since the early 1900s, and were one of the first devices that could play recorded music (the other one being the phonograph).

You load your pianola with paper rolls which have tunes encoded on them in the form of little holes, and a mechanism inside the piano plays the tunes for you. Very interesting. And, when you find that there is a pianola available for free just down the road, what do you do? Answer – you borrow a trailer, drag the pianola home (plus a goodly number of music rolls), and then become enthralled with the sound that it makes. So, part Western saloon, part Victorian parlour.

Figure 1 shows my first pianola. The hole in the middle is where you load the music roll. Then you pump the pedals and the piano plays itself. You can control the speed of the playback and the volume of the sound using the controls on the front of the piano. You can use it as a normal piano too. **Figure 2** shows a roll of piano music: '*Hawaiian Nightingale*'. The legend 'Hand Played' on the label means that the music was recorded from a live performance rather than transcribed onto the paper from the written musical score. Hand-played music sounds better because a human player can add more expression and 'syncopation', which means playing the notes slightly off the beat.

Figure 3 shows the insides of another pianola I seem to have acquired (they are addictive). This one needed some serious pneumatic repairs, as the brightly coloured pipes will testify. The three vertical panels on the right-hand side of the piano are driven by a crank at the top, and connected to the bellows which power the note playback.

The music roll is powered via a complicated set of gears and chain drives, and pulls the paper strip over a reader in the middle of the piano. The reader contains 88 holes, one for each note. Normally, each hole is blocked by the paper in the music roll. When a hole in the paper goes over the reader, however, it lets air into the reader, triggering a tiny set of bellows which moves the piano mechanism for the note controlled by that track. →



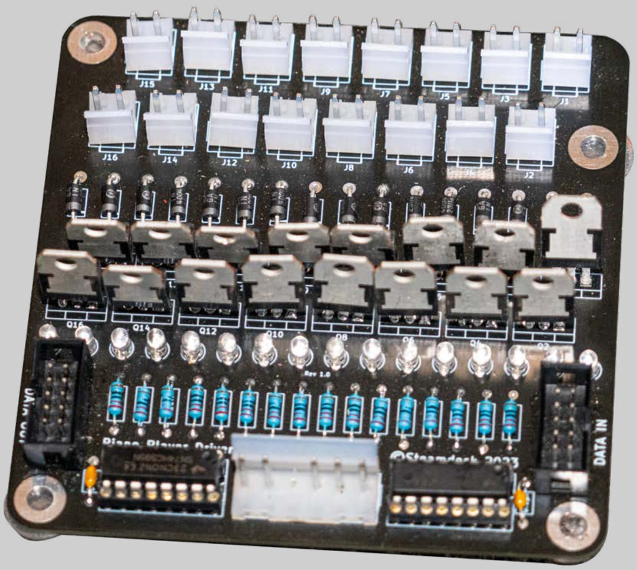


Figure 5 The driver board was made the same size and shape as a drinks mat, so that if the design was faulty, we would at least have some nifty drinks coasters

THE PIANOLA LIFE

So, now I have multiple pianos, including one which will play itself. This is fun! Although, a pianola is a high-maintenance device. I must do all the piano-related fixes, making sure that the strings are tuned to the right notes, that the felts (which damp the strings when a key is released) are in good condition, and the keyboard mechanism works correctly. But I also need to deal with the huge number of tiny rubber tubes and bellows which transmit the air pressure to trigger the notes, and then ensure that the drive mechanism, which pulls the paper roll through the pianola, is working correctly and moving the paper at 70 inches per minute.

Eventually, after a lot of work, the pianola becomes a part of the furniture, and I enjoy working my way through the music rolls that came with it, hearing songs that might not have been played for many years. And then I start to wonder if there is a way of making a piano which could play MIDI files directly, rather than needing specially made paper rolls (although a surprising amount of contemporary music is still released on this format). So, why not convert a piano to understand MIDI notes? And so, that's what I did.

MAKING A MIDI PLAYER PIANO

Figure 4 shows my first experiment with a computer-controlled keyboard. This involved using servos to play piano notes. This was discovered to be workable, in that you can use the arm on the servo output to make a piano key move, but the movement is too slow to be properly usable. So, the next step was to look for some suitable solenoids.

A solenoid is made up of a coil of wire and an internal core which is pulled into the coil when you pass current through the latter. I use this movement to 'press' a key, although there are some slight complications. The solenoids I'm using have coils with an internal resistance of 8 ohms and are powered by a 12-volt supply. If I do the sums with Ohm's law, I discover that each coil draws 1.5 amps. A standard piano

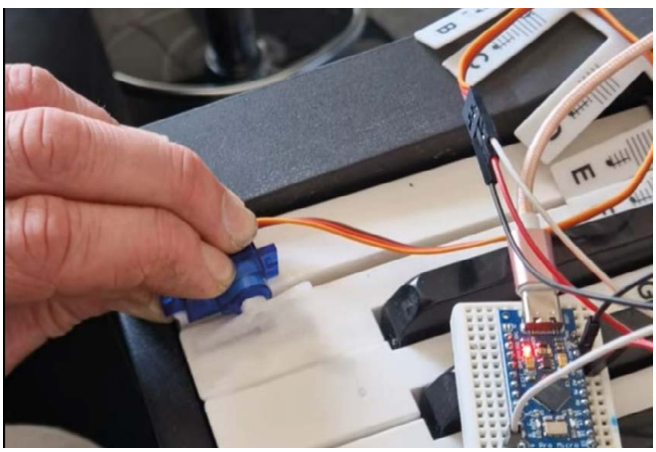


Figure 4 This might look simple, but the video of it did attract several thousand views

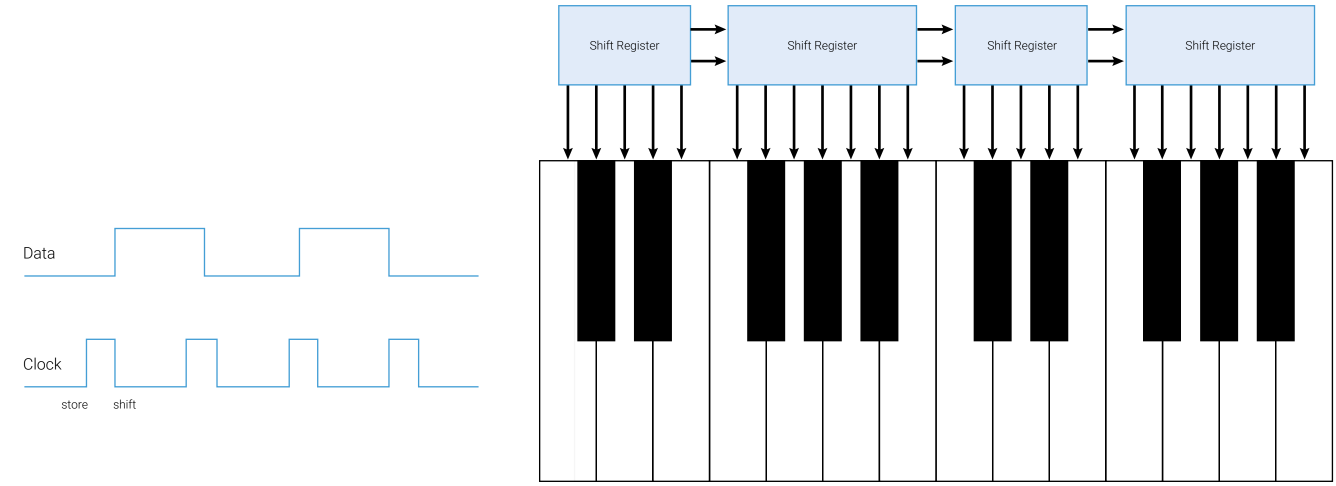


Figure 6 ↑
Three shift registers can control two octaves

has 88 keys, which means that in a worst-case scenario, with all the notes played at once, the piano would draw more than 120 amps at 12 volts. I decide not to think about this too hard and order a 50-amp, 12-volt power supply on the basis that no more than 30 or so notes will be sounding at the same time. After all, a piano player only has ten fingers…

CONTROL THE POWER

Now that I have a power supply and some solenoids, I need to think about how I can control the power for each note. The good news is that there are circuits online to help with this, and the better news is that colleagues at the office are keen to help with the creation of circuit boards that can be used to control a bunch of notes. We design a circuit board and get some made, and we also order all the components.

Figure 5 shows a completed driver board which can drive 16 solenoids. There are six of these boards in the piano, connected in a 'daisy chain', with the output of one board connected to the input of the next. The components at the bottom of the board in **Figure 5** are 8-bit shift registers which hold the signal states to be sent to the MOSFET drivers which control the solenoids.

SHIFTY BUSINESS

Figure 6 shows how the shift registers are loaded with note information. Each shift register has 'clock' and 'data' inputs. The microcontroller sends the note data into a register by moving a clock signal up and down. When the clock signal rises from low to high, the shift register samples the input data and stores it in one bit. When the clock signal falls, the register shifts its contents along one bit. The result of the waveform in **Figure 6** would be to set the first four keys to the pattern '1010'. In other words, the keys C and D are pressed. A shift register also has a clock and data outputs which can be passed on to another shift register to allow longer bit patterns to be stored. After 88 clock pulses, all the registers would be loaded with a pattern of signals that represents all the keys on the keyboard.

Each shift register also accepts an 'output enable' signal. When this signal is set low, the register will output its data values onto the output pins of the chip. These signals are used to control MOSFET switches which send power to the solenoids. There is also a 'reset' signal which can be used to clear the contents of the shift register.

Each time the keyboard needs to be updated, the microcontroller sends a new set of clock and data signals, and the new values are then latched onto the outputs. →

QUICK TIP

It turns out you can pick up second-hand pianos (and even pianolas) for tiny amounts of money. In fact, people are so keen to get rid of them that if you offer to go round and pick it up, you can often get it for free.

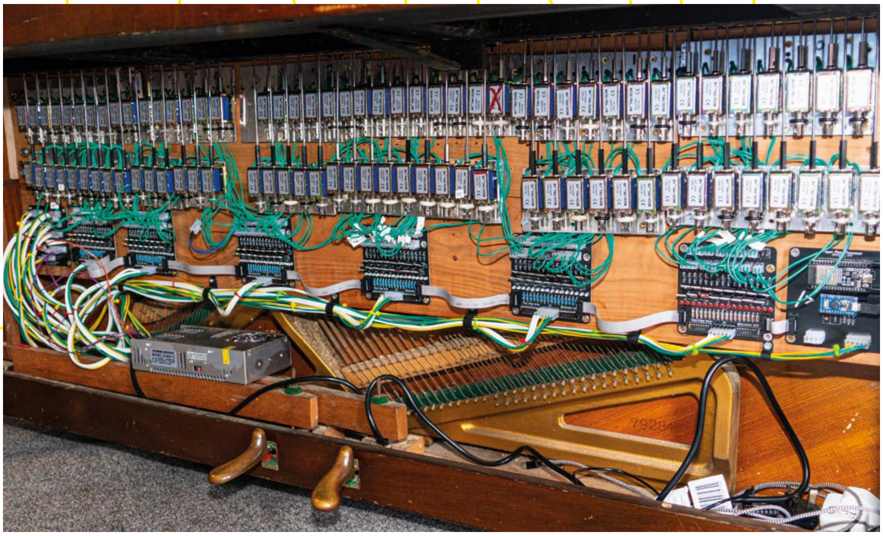


Figure 7 The last half of the final driver board is not used as there are only 88 keys

Figure 8 The hammers for each note are above the shiny metal bar going across the middle of the picture

MAKE A NOTE OF THIS

Figure 7 shows the complete player piano electronics. The solenoids are mounted on aluminium carriers. Each solenoid has an actuator which goes up through a hole drilled in the piano. When the solenoid is triggered, the actuator moves up through the hole and pushes against the underside of the piano key.

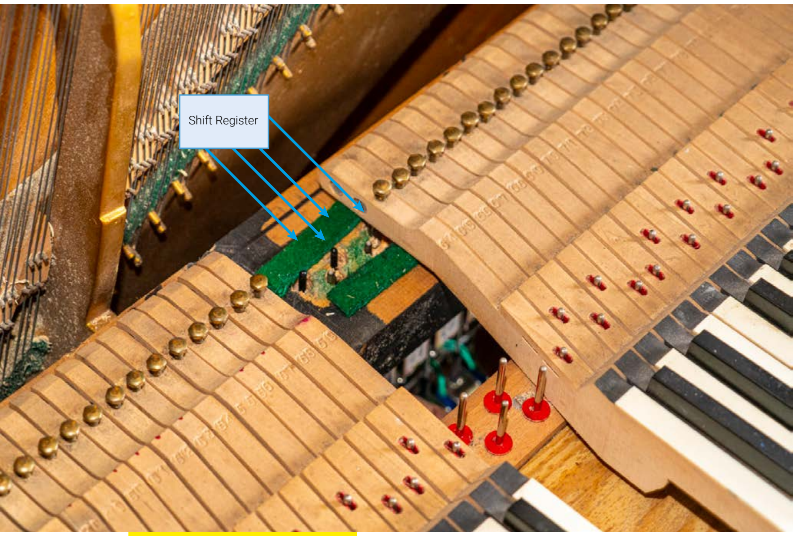
Figure 8 shows how a piano works. Each piano key is a tiny see-saw. When you press down on the front of a key, the back of the key goes up, hitting a mechanism causing a hammer to hit a string and make a note.

When you let go of the note, the back of the key goes down, releasing a small felt pad which then rests against the string, stopping the sound. It is quite a complicated mechanism, and it is repeated for each of the 88 notes on the piano keyboard. It is said that a piano contains 12,000 different parts. Looking at **Figure 8**, you can begin to see how this is the case. The electronic piano uses the actuator from a solenoid to push the back of the key up and sound the note.

Figure 9 shows the piano keyboard with four keys and the hammer mechanism removed. The figures shows the actuators on the ends of the solenoids. When the actuator goes up, it hits the bottom of the key and moves it up, playing the note. The holes had to be drilled in a staggered formation because the width of each solenoid was greater than the width of a piano key.

MIDI OF THE ROAD

The final link in the chain is the microcontroller, which provides the MIDI interface to the outside world and generates the data signals for the shift registers. **Figure 10** shows the controller board, along with one of the solenoid controller boards. The clock and data signals for the shift registers are generated by an Arduino Pro Micro. This device supports 'USB hosting', which means it can appear to an external device as a MIDI peripheral and accept note on and off messages. The ESP32 device above it on the circuit board is used so that the piano can also be used via Bluetooth MIDI.



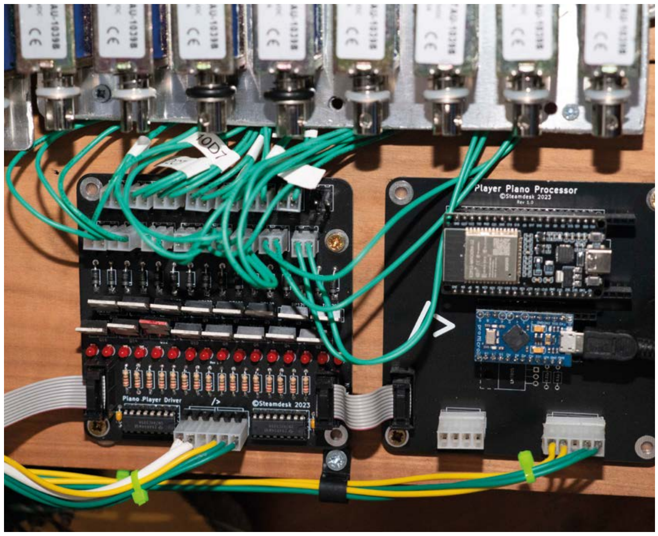


Figure 9 ↑
Each key needs to be individually adjusted so that the keyboard doesn't look 'snaggle-toothed'

Figure 10 ↗
The controller board is on the right of the picture

Figure 11 ↘
The piano is always a hit when I take it out to demonstrations

THE THING LIVES!

The piano is becoming a bit of a star with quite a following on YouTube. **Figure 11** shows it being demonstrated at the Rural Lincolnshire Enterprise Hub. It has acquired some remote-control facilities, courtesy of an Amazon Alexa interface which lets you ask for tunes by name and have them played. I've also been looking at using generative AI to create music with a particular style on demand. It would also be interesting to find a way of reading pianola rolls so that they could be converted into MIDI notes to be played on the piano. And finally, I'm exploring adding coloured lights to the keyboard. Everybody loves coloured lights.

If you want to follow along with my journey, you can find the pages for this project at **playerpianos.co.uk**. There are videos of the piano in action, more of the story behind it, hardware designs for the interface printed circuit boards, and even a place to chat about piano stuff.

The project has been a lovely example of how you can start with something simple (I'd really like to learn a bit about the piano) and end up with a working knowledge of piano history, get a mechanical pianola (or two) of your very own, and then branch out into electronic control, the MIDI protocol, and even artificial intelligence. It's been great fun, and I think we have only just started… □

HackSpace magazine meets...

Toby Roberts

Raspberry Pi's own maker in residence

Toby gets to play with things all day long. The only constraint on him is that he has to "make something cool". Toby gets to hang out in his own personal maker space all day, where he jealously guards the equipment like the dragon Smaug sitting atop his hoard of trinkets. Not only does he make cool things, but he's also responsible for making sure that nobody who ventures down to the Raspberry Pi maker space accidentally slices their finger off.

He makes big things, small things, shiny things, things that fly, things that roll, things that flash... pretty much all the things you can do with a microcontroller and a load of 3D printers.

We got to hang out with him downstairs in the Raspberry Pi maker space, where there are a load of power tools we're not allowed to touch (in case we slice a finger off), to find out what he's been up to. →

Below Is it just us, or does that Lego man look like he knows something that we don't?

HackSpace: First question: How does one get to be a maker in residence at Raspberry Pi? How did I miss that job advertisement?

Toby Roberts: I joined Raspberry Pi just over two years ago as a documentation writing assistant, and started to write tutorials for the Raspberry Pi. I've always had a personal interest in 3D printing and laser cutting, so I was quite happy to make things to go with the tutorials.

And whenever anybody wanted something making, I would always put my hand up. A good example is when we went to SiliCon convention in San Francisco a few years ago; they wanted something Pico-based to take with them to show off the Raspberry Pi Pico. So I made a lightsaber, which went down a storm.

In fact, I made several lightsabers, and then that sort of snowballed. From there, I continued to write tutorials, but eventually, I was asked if I wanted to be a maker in residence full-time, and I jumped at the chance.

HS: Can you choose the colour of the lightsaber? Can you go Darth Vader red or Mace Windu purple?

TR: The lightsaber wasn't my design at all: that was an Adafruit project based on the RP2040 chip as the main brain. It used one of Adafruit's add-on boards, the Prop-Maker Feather board, which has an audio amplifier on board, a motion sensor, and an output for NeoPixels. So when you wave it around, you get that noise that we've all made when we were kids playing with cardboard tubes or sticks or whatever, pretending to be Luke Skywalker.

HS: Do you have a palatial maker space here in the Raspberry Pi office?

TR: It started [as a] one-man operation in the shed at home, where I had a laser cutter and printers and tools etc.; now I'm in a very swish building where I was allocated a space for the maker lab and was asked to fill it with lots of wonderful toys.

We've got three FDM (fused deposition modelling) printers: an UltiMaker S5, an Ender-3, and the latest addition, which is a Bambu Lab A1 mini.

The Ender-3 has been, for a long time now, the go-to choice for hobbyists. But if there's anybody out there who knows about Ender-3s, they're also quite tricky to work with, and they require a lot of tinkering.

> "When you wave it around, you get that noise that we've all made when we were kids"

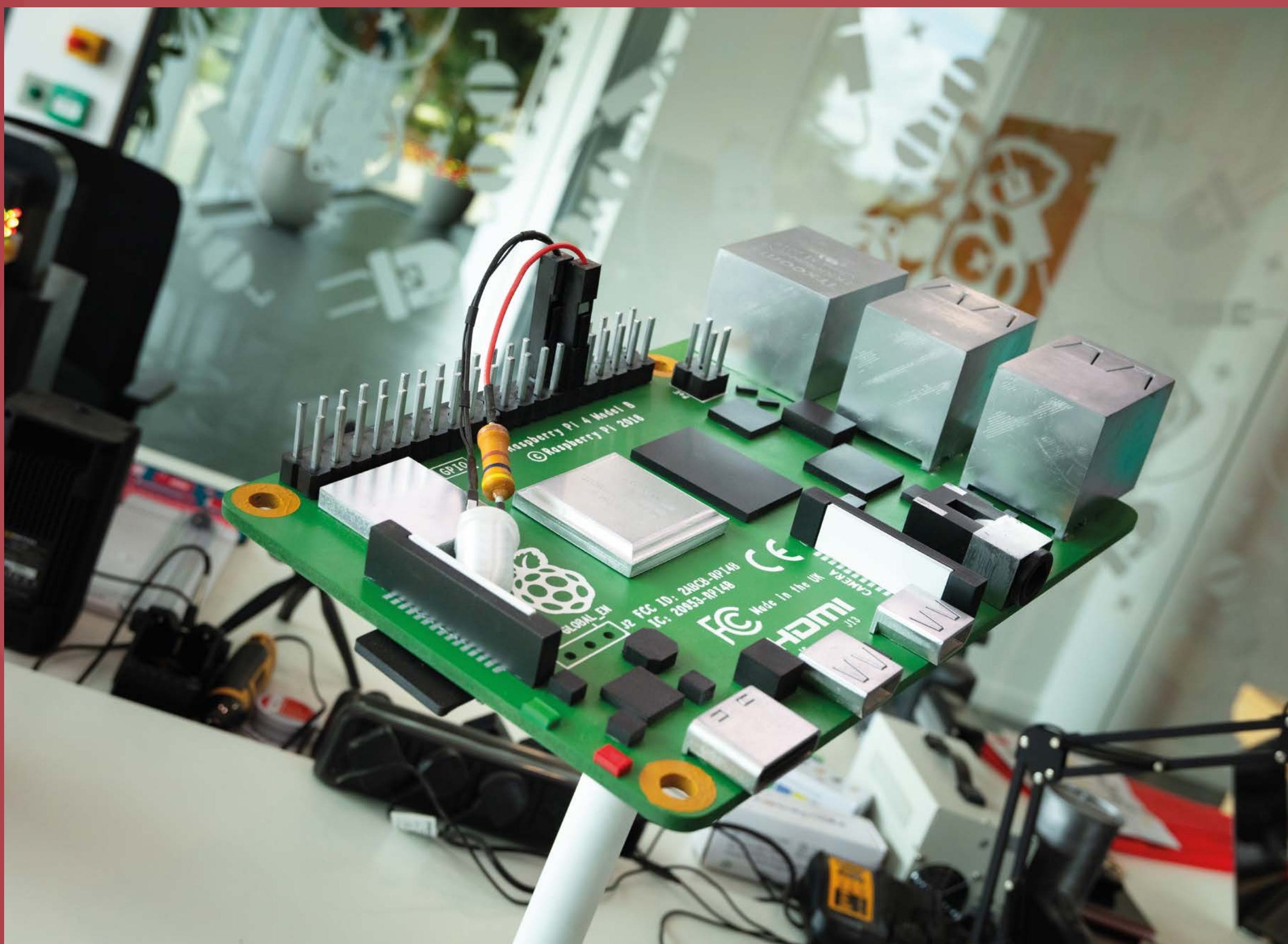
They're great, and I love them – that was the first 3D printer I had – but they can be a pain to keep going. So we got an UltiMaker S5, which is a bit more of an industrial machine, a bit more of a workhorse.

The two of them are a great combination, but we also wanted a printer that we could take to trade shows and the like to show off things that you can print that work with Raspberry Pi, because 3D printing and Raspberry Pi go hand in hand really well. And that little Bambu A1 mini, I have to say, is fantastic. Bambu Labs has taken 3D printing to another level – they seemed to start an uptick in quality of 3D printing. It's on sale for £169 at the moment, which is phenomenal value. I can't fault it – it's got resonance testing, so it caters for the vibrations in the machine. It's got a camera, remote viewing, Wi-Fi, touchscreen, and linear rails. It's got a slightly smaller print area, but it's incredibly fast and produces prints that are second to none. I very much wanted to show that anybody can get involved in making, and for the money, that's the best printer I've ever used.

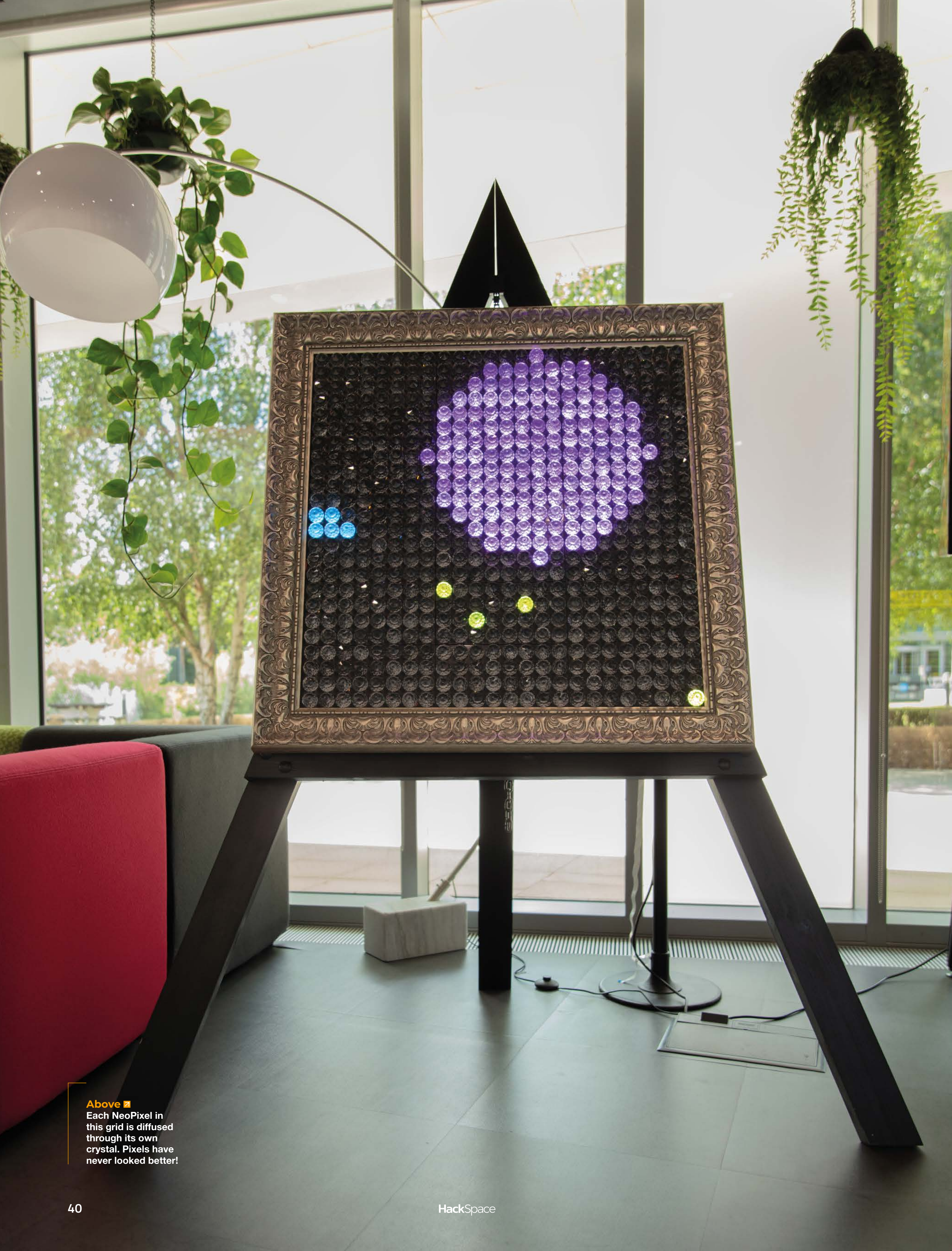
We've got two resin 3D printers: an ELEGOO 4K 3D printer and a Sonic Mega 8K, which is the same kind of machine, just with a bigger build platform. There's a wash station, and a curing station for things that we've printed on the resin printer. And then we've got a WorkBee CNC machine, which is a kind of high-end hobbyist machine. It's got a build area of half a metre square that comes in kit format. It took me nearly a week to build. Then we've also got a very, very large laser cutter, which is an HPC laser cutter with a cutting area of 1200 × 900 millimetres. We had to take it apart just to get it through the door. But I'm really glad we got the big one, because I've already used it to make some big projects, big logos, and signage for the building. So its size is coming in really handy, and I love it. It's a really great piece of kit.

HS: There's an enormous Raspberry Pi behind you. Does it work?

TR: Kind of! That came about because we were asked by the Grand Arcade shopping mall in Cambridge to produce something to exhibit on behalf of Raspberry Pi for an exhibition they were putting together where they were displaying things that have come out →



Above
On Toby's watch, computers are getting bigger and less powerful: this giant Raspberry Pi just flashes an LED on and off – Moore's Law be damned!



Above
Each NeoPixel in this grid is diffused through its own crystal. Pixels have never looked better!

of Cambridge, and we were given a small plinth to put something on. And it struck me that the obvious thing to build would be a giant Raspberry Pi.

So we've got a combination of laser-cut and 3D-printed parts, with an MDF sheet to act as the giant printed circuit board. A lot of sanding and spray painting then followed to produce a giant Raspberry Pi. I even made a giant SD card, and put the logo and all the little signage on there. Even though you can't see it, I had to do it.

HS: That reminds me of Pimoroni, and the detail that goes into their products. Even the bits you never see are gorgeous.

TR: The reason it works only 'sort of' is that we've got the obligatory flashing LED working. I printed the shape of a giant LED and put a strip of NeoPixels in there, which is powered and controlled by a Raspberry Pi Pico, which I've got hidden away at the base of the build. When anybody buys a single-board computer or a microcontroller for the first time, the first project you do is flash an LED. So I had to throw that on there, because it's the law: you have to flash an LED when you buy a new microcontroller. I still do it today – every time I get a new product, the first thing I do is run a blinking program, right?

HS: A blinking LED moves us very nicely on to this lovely-looking object. It looks like you've put LEDs inside a load of gemstones.

TR: When we moved into our new building, we suddenly had a very grand lobby area, so I got to make something to fill the space and look nice. I had seen NeoPixel displays before – lots of people have made arrays using interesting things to diffuse the light, like ping-pong balls, or else 3D-printed something to make the light opaque and have an LED shine through it, that kind of thing. So I wanted to do something along those lines. My first thought was: how can I make it a bit different to anything I've seen before? What would I use as a diffuser? I tried a lot of different things, and eventually settled on these glass crystals, which are about two and a half centimetres in diameter – they're made for chandeliers and that kind of thing. I bought some and mocked up a strip of NeoPixels, and behind every glass crystal was one NeoPixel.

> "It's the law: you have to flash an LED when you buy a new microcontroller"

It's a 24×24 array of NeoPixels – 576 in total. Each NeoPixel has a crystal in front of it, and they're all housed in 3D-printed-and-designed mounts, and then there's a large frame around the whole thing. I built an A-frame easel-type structure to hold this mammoth display up, because it weighs an absolute ton because the crystals [are] all glass.

On the programming side, I use a Python script to control the NeoPixels as a display. So I can scroll text across the display; I can display images. I've got fireworks going off on it, and I can play games with it. I've programmed Pong, Space Invaders, Snake, and hooked up a Raspberry Pi Pico-powered game controller, which is excellent for playing the games. And because it's programmable, I've asked the Raspberry Pi engineers to contribute, and they've provided me with scripts to run on it so that we can keep it fresh and interesting for people visiting Pi Towers.

HS: And there's a rocket behind you.

TR: This came about because a colleague stumbled online across a board that somebody had designed around the RP2040 chip, to go into model aircraft. It's got a pressure sensor for altitude; it's got accelerometers, temperature, etc., so you can use it in either model aircraft or rockets. You launch it, and it records to an SD card, and then you retrieve the data afterwards, so you can work out exactly what the board recorded.

I hooked up with the East Anglian Rocketry Society and arranged to spend the day with them. And in the meantime, built my own rocket based on an Estes Egg model rocket – they call it an egg because the idea is that it's designed for students to get into model rocketry, and you have a payload section into which you put an egg. The idea is to launch your rocket and return it safely to earth without breaking the egg. Mission accomplished!

Instead of an egg, I've designed and 3D-printed a housing that contains the PCB that this chap designed, but which also hooks up to a Raspberry Pi Zero 2 W and a Raspberry Pi camera so that we can record the footage of the rocket. So we went along and launched it and got the data back. It didn't go particularly high, because I didn't want to lose it, but the telemetry, the data that came back was fascinating. The board was designed by a guy who goes by Dan Invents, and the rocket that we fired went about 145 metres.

HS: And who's this?

TR: So recently Raspberry Pi celebrated its 12th anniversary. There was a big Raspberry Jam in Cambridge, and we went along to exhibit some of our wares and talk to other people about Raspberry Pis. I was asked to make something fun, so I decided to make a giant Lego figure. In a CAD program I modified various different 3D renders of a Lego man, made it more suitable to 3D print and more suitable to house a Raspberry Pi inside, →

with a servo board on the top to control the three servos: one for each arm and one for his head.

I developed a web interface so that I could control him remotely from my mobile phone, just by connecting to the hotspot on the Raspberry Pi. And then I had a little GUI on the screen and my mobile phone so I could press up, down, left, right for his arms, or I could press dance, and he does a little dance. There's nothing externally that's different than the standard Lego man figure, but inside, I've created voids and cavities that house the servos and the Raspberry Pi.

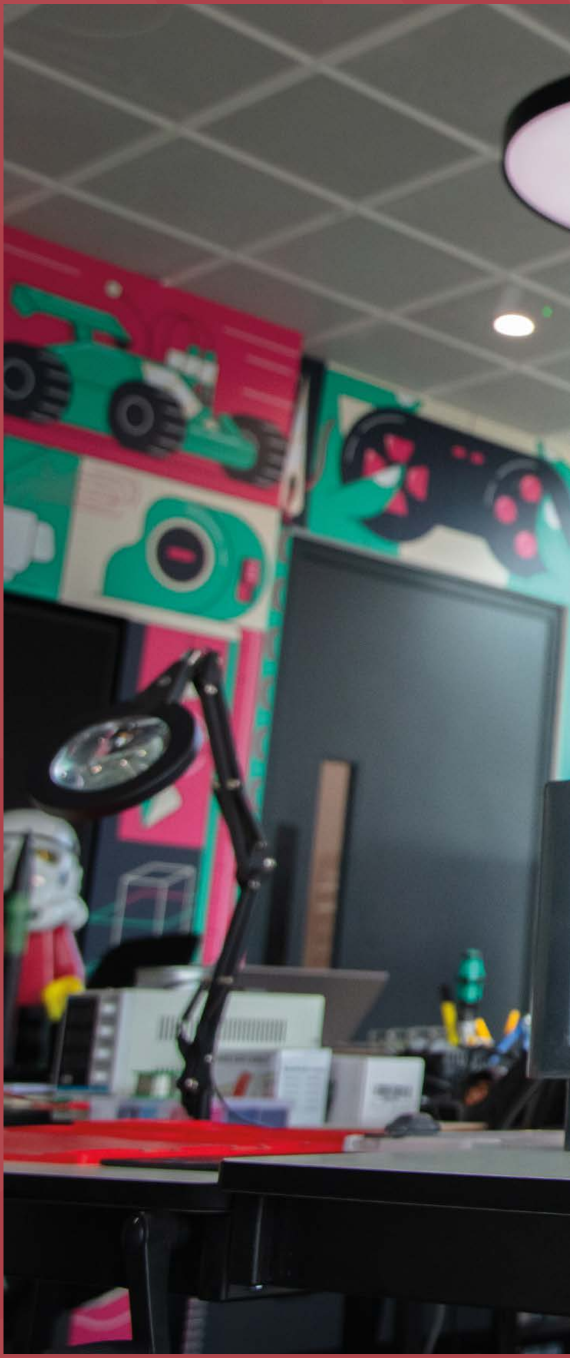
> It's a kind of throwback to the 1980s, and it plays music, and it talks just like the computer did in the film

HS: What are you working on at the moment?

TR: Are you familiar with the 1983 film *WarGames*, starring Matthew Broderick? It's about a young lad who hacks computers in an effort to try and steal the latest games, and he accidentally stumbles on a government computer and triggers the countdown to an electronic Armageddon. In the movie there's a supercomputer that takes the place of humans in dictating what would happen in the event of World War 3. It's called WOPR: War Operation Plan Response, and I decided that it would be fun to reproduce a model of WOPR but put a bit of fun into it. There's a Raspberry Pi inside controlling NeoPixels, which display red and yellow in typical 1980s computer fashion. There's also a Raspberry Pi touchscreen so that I can actually play clips from the movie. But also, I've got it so that it plays clips from other 1980s movies. So it's a kind of throwback to the 1980s, and it plays music, and it talks just like the computer did in the film. It's a combination of 3D-printed parts and laser-cut MDF and wood, all glued together, sanded and sprayed to produce a fictional 1980s supercomputer.

HS: Do you ever use anything non-Raspberry Pi?

TR: I've used Raspberry Pis since before I joined Raspberry Pi as an employee. I tried almost every single-board computer or microcontroller out there, of all different fruit varieties, and always came back to Raspberry Pi – that was way before I had any idea that I would end up working for them, because I always found that the hardware was reliable and worked out of the box. And if I had a problem, there was always somebody in the community who would help with a particular issue, and I would get it resolved. The number of other single-board computers that have ended up in the bottom of my drawer never to be seen again is quite extensive, but I always came back to Raspberry Pis.



Above The WOPR is the stuff of a 50-ish-year-old computer geek's dreams; which is why Toby made one!

REGULAR

Objet 3d'art

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

3D printing has revolutionised manufacturing. It's really incredible that you can go from idea to physical model with a machine that costs just a few hundred pounds. If you have an idea, you can test it out there and then, making your own prototypes for pennies. Despite that, a lot of the impressive 3D prints we see are… less than 100% functional.

One of those 'because it's there' prints is this giant Lego man by Toby Roberts. He was brought forth into the world in standard PLA on an UltiMaker S5 3D, which took several days of printing. He's not just a useless lump of plastic: thanks to a Raspberry Pi Zero 2W, a SparkFun Servo pHAT, and three MG996R servos, he can turn his head and move his arms back and forth. Actually, we take back what we said about him not being useful: we might see if he's free to do a little freelance work as a scarecrow on our allotment. □

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**

TREASURE HUNT

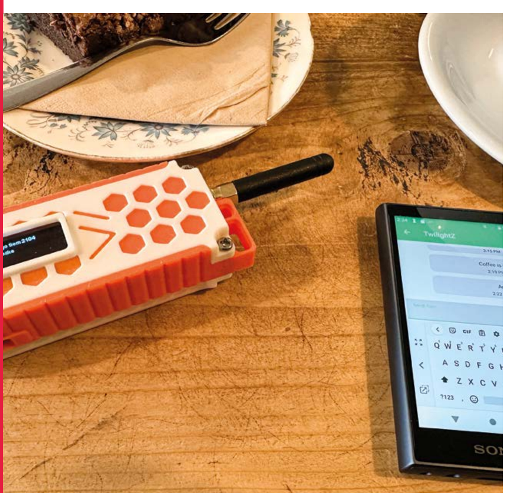
The RFID game for HackSpace mag issue 80 looks great. I love hiding stuff around the place and setting my kids loose finding it. The trouble is, the easy option is to put chocolates out, and then a wholesome activity quickly becomes a calorie-fest.

There are so many twists you could put on the RFID version to keep things entertaining. I've already started planning my build.

Carl
Macclesfield

Ben says: Having set up a few treasure hunts before, it's so easy to get drawn into the 'treasure' being either packed full of sugar or plastic tat that's doomed to end up in landfill. Any other option tends to either struggle to excite kids, or quickly becomes expensive.

As well as this RFID game, geocaching is a fun adventure with kids where they have to find secret stashes, and they get to add their names to a logbook.



MESHTASTIC

The problem with decentralised telecommunications networks is that centralised ones are just much easier to use, until suddenly they aren't. Rob Miles' tutorial on Meshtastic got me thinking about this recently. To be honest, I don't really have a need for a decentralised network, but I like the fact that this one exists. As Gandhi famously (might have) said, "Be the change you want to see in the world".

Well, I want to see decentralised networks, so I've just ordered the parts to build my own Meshtastic node.

Harry
Watford

Ben says: The problems with centralised networks often seem abstract and hard to imagine until some situation renders them very real. Amateur radio has long been the decentralised system of choice, and it's got plenty of things going for it, but the requirement of an exam and licence puts a lot of people off. Meshtastic is a great and easy way to get started. Let's hope the network continues to grow.

PHOTOGRAMMETRY

I'm frankly stunned that you can get 3D-printable models from photo scanning using just a smartphone. It almost feels like something off *Star Trek*. Wave your communicator around, press a button and, a bit later, you can replicate the thing. I know we're living in the future (at least compared to when I grew up), but this really seems magical.

Claire
London

Ben says: As Arthur C. Clarke once wrote, "Any sufficiently advanced technology is indistinguishable from magic". It feels like we're living in a strange time where technology is advancing rapidly, but at the same time many things are stagnating or getting worse as people try to game systems and large companies seek to entrench their positions rather than innovate. Internet search seems to be going backwards, and AI-generated nonsense is filling the web, yet we can capture 3D scenes in a short one-minute video.

GUITAR

Andrew's guitar looks like such a fun project. It looks like there are loads of little bits to geek out over, and one of those builds you can really take your time with and enjoy the process. Of course, this might have something to do with the fact that I'm retired and can spend a happy day poking frets into position without having to worry that I should be using my time doing something more productive.

Dan
Bolton

Ben says: At one level, guitars are really simple – half a dozen wires suspended over coils – yet at the same time, every little detail can have a significant bearing on how well it performs. This means you can make it as complex or simple as you like, but you have to live with the consequences of your decisions. The key thing is to match your guitar project to your skill and time. There's loads of fun to be had in an afternoon cigar box build, and also loads of fun to be had in a complex build that take months.

FORGE

HACK | MAKE | BUILD | CREATE

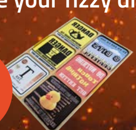
Improve your skills, learn something new, or just have fun tinkering – we hope you enjoy these hand-picked projects

PG 54
CROCHET
Turn maths into objects

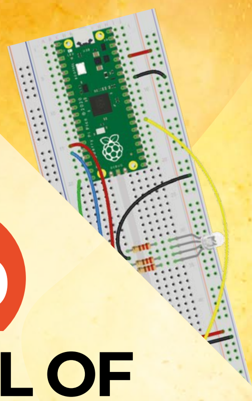
PG 58
KICAD TIPS
Get the most out of your PCB design

PG 62
METAL BALLS
Hammer your way to spherical perfection

PG 64
UPCYCLE CANS
Upgrade your fizzy drink detritus



PG 70
DOING A JIG
Build better with temporary fixtures

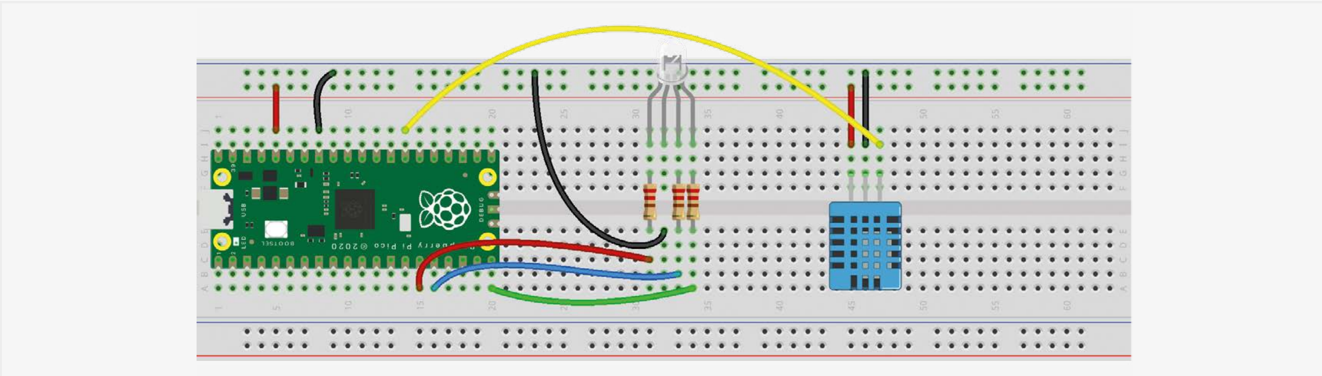


PG 50
SCHOOL OF MAKING
Start your journey to craftsmanship with these essential skills

50 Colour-changing LED

PG 76
ROBOT ARM
Build you own dexterous robot

PG 80
NO CODE LEDS
Create animated effects without programming



Temperature-controlled colour lamp

This easy-to-make electronics project combines a Raspberry Pi Pico, temperature sensor, and RGB LED

Phil King

A long-time Raspberry Pi user and tinkerer, Phil is a freelance writer and editor with a focus on technology.

Figure 1
The wiring diagram for connecting an RGB LED and DHT11 sensor to the Raspberry Pi Pico; double-check the pin ordering on your LED and sensor, as it may differ

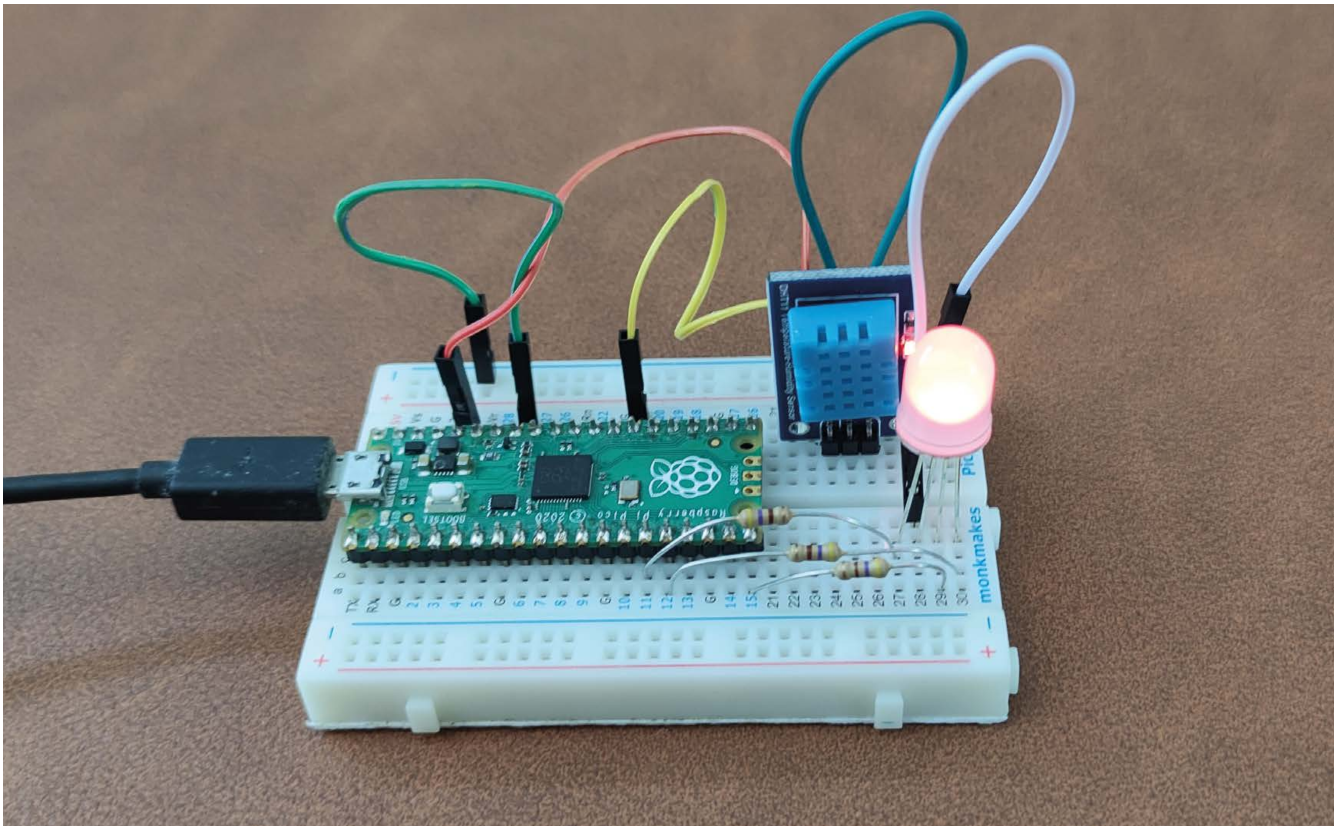
Once you've mastered controlling the brightness of a single-colour LED by altering the duty cycle of a PWM (pulse-width modulation) signal, switching up to an RGB LED is the next logical step. In essence, it's three LEDs in one: red, green, and blue. By combining varying brightnesses of each, you can create any shade in the RGB colour space.

You can get your RGB LED to follow a preset pattern of colours, or control it using an input device. Here, we're using the temperature reading from a basic DHT11 sensor.

First, let's wire up the RGB LED to our microcontroller – we're using a Raspberry Pi Pico here, but the principle is the same. The common-cathode RGB LED has four legs: one for each colour channel and a longer leg for the ground connection. As you can see from the wiring diagram (**Figure 1**), we connect each colour channel to a GPIO pin via a 470Ω resistor.

Once the RGB LED is wired up, it's best to check it's all working in the expected way by running a simple MicroPython program.

```
from machine import Pin, PWM
from time import sleep

# Set PWM pins to control R, G, and B LEDs
pwm11 = machine.PWM(machine.Pin(11))
pwm15 = machine.PWM(machine.Pin(15))
pwm12 = machine.PWM(machine.Pin(12))
pwm11.freq(1000)
pwm15.freq(1000)
pwm12.freq(1000)

# Loop to light R, G, B LEDs in turn
while True:
    # Red
    pwm11.duty_u16(65535)
    sleep(0.5)
    pwm11.duty_u16(0)
    sleep(0.5)
    # Green
    pwm15.duty_u16(65535)
    sleep(0.5)
    pwm15.duty_u16(0)
    sleep(0.5)
    # Blue
    pwm12.duty_u16(65535)
    sleep(0.5)
    pwm12.duty_u16(0)
    sleep(0.5)
```



Above
The project wired up on a half-size breadboard. As the temperature reading from the DHT11 sensor changes, the program alters the shade of the RGB LED accordingly

Here, we start by importing the **`Pin`** and **`PWM`** methods from the **`machine`** library. To control timings, we import the **`sleep`** method from the **`time`** library. We then assign three GPIO pins as PWM outputs and set the frequency level (it won't work without this). Finally, we use an infinite **`while True:`** loop to light each colour element in turn.

Note that some RGB LEDs may have the colour channels in a different order. So, if you find yours is different, you can either change the wiring or the pin assignment in the program to swap the colour channels accordingly.

FEEL THE HEAT

Now the RGB LED is working, it's time to add the temperature sensor. We're using the basic DHT11 type here, but you could use the more accurate DHT22. The sensor has three pins: power (VCC) and ground, along with a digital output (DOUT) pin. As in **Figure 1**, we connect the former two to 3V3 and GND pins on the Raspberry Pi Pico, and the digital output to a GPIO pin. With the sensor connected, let's test it out…

```
import dht
from machine import Pin
from time import sleep

#sensor = dht.DHT22(Pin(21))
sensor = dht.DHT11(Pin(21))

while True:
  try:
    sleep(2)
    sensor.measure()
    temp = sensor.temperature()
    hum = sensor.humidity()
    print('Temperature: %3.1f C' %temp)
    print('Humidity: %3.1f %%' %hum)
  except OSError as e:
    print('Failed to read sensor.')
```

Here, we're using the **`dht`** library to take readings. We assign pin 21 to the DHT11 sensor (uncomment the DHT22 line instead if you want to use that). Then, in an infinite loop, we take a sensor measure and assign variables to the temperature and humidity readings, which we then print to the Shell. The temperature is in Celsius by default; to change it to Fahrenheit, you can convert it with the formula, **`temp = temp * (9/5) + 32.0`**. →

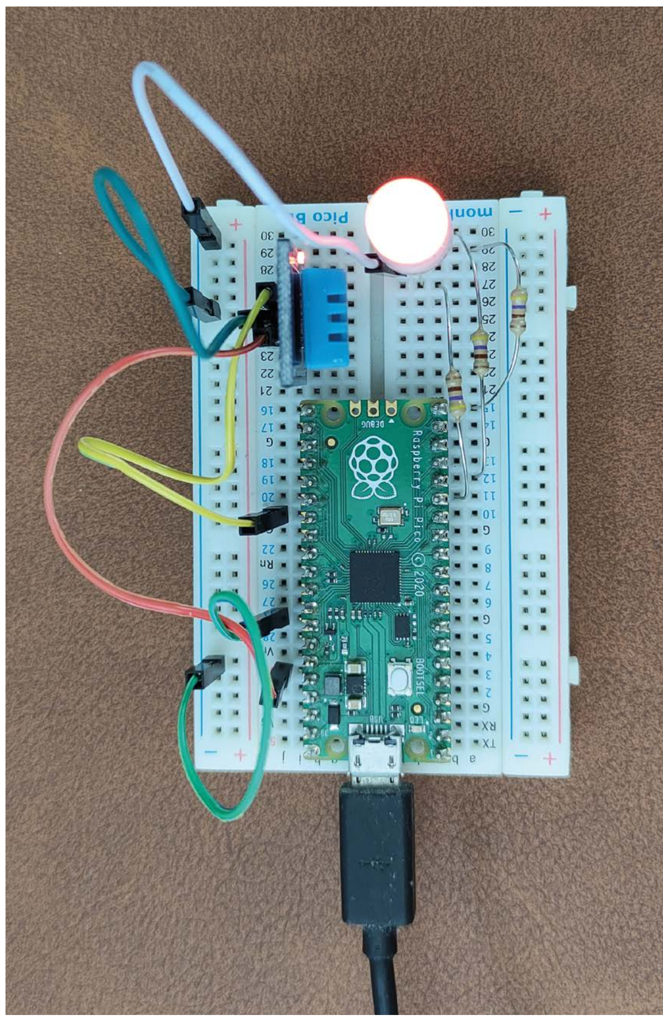
Right By varying the PWM duty cycles for the red, green, and blue channels/pins, we can alter the colour of the RGB LED to virtually any shade

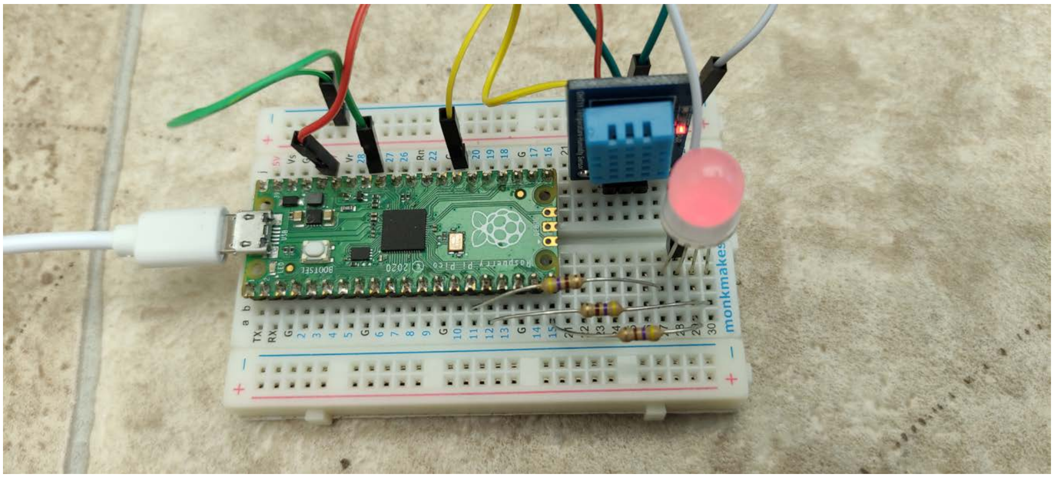
TEMPERATURE RANGE

Finally, we'll use the sensor's temperature reading to set the colour of the RGB LED. The simplest way to do this would be to create a function to set a different shade for several temperature ranges. For instance:

```
def set_rgb():
    if temp < 6:
        #set LED colour to blue
        pwm11.duty_u16(0)
        pwm15.duty_u16(0)
        pwm12.duty_u16(65535)
    elif temp < 15:
        #set LED colour to yellow
        pwm11.duty_u16(40960)
        pwm15.duty_u16(24576)
        pwm12.duty_u16(0)
    elif temp < 22:
        #set LED colour to orange
        pwm11.duty_u16(57344)
        pwm15.duty_u16(8192)
        pwm12.duty_u16(0)
    else:
        #set LED colour to red
        pwm11.duty_u16(65535)
        pwm15.duty_u16(0)
        pwm12.duty_u16(0)
```

Right As the temperature gets higher, the RGB LED changes colour. Here it has reached red, which means it's pretty hot (for the UK) – alter the ranges in the code to suit your own location





Another option is to create a colour gradient effect; with this, the LED changes shade slightly with each degree increase in temperature, going from blue, through shades of green, yellow, orange, and red. This is achieved by varying the PWM of each RGB element according to the temperature only within a certain range (or two in the case of green, so its level increases then decreases), as in the following code:

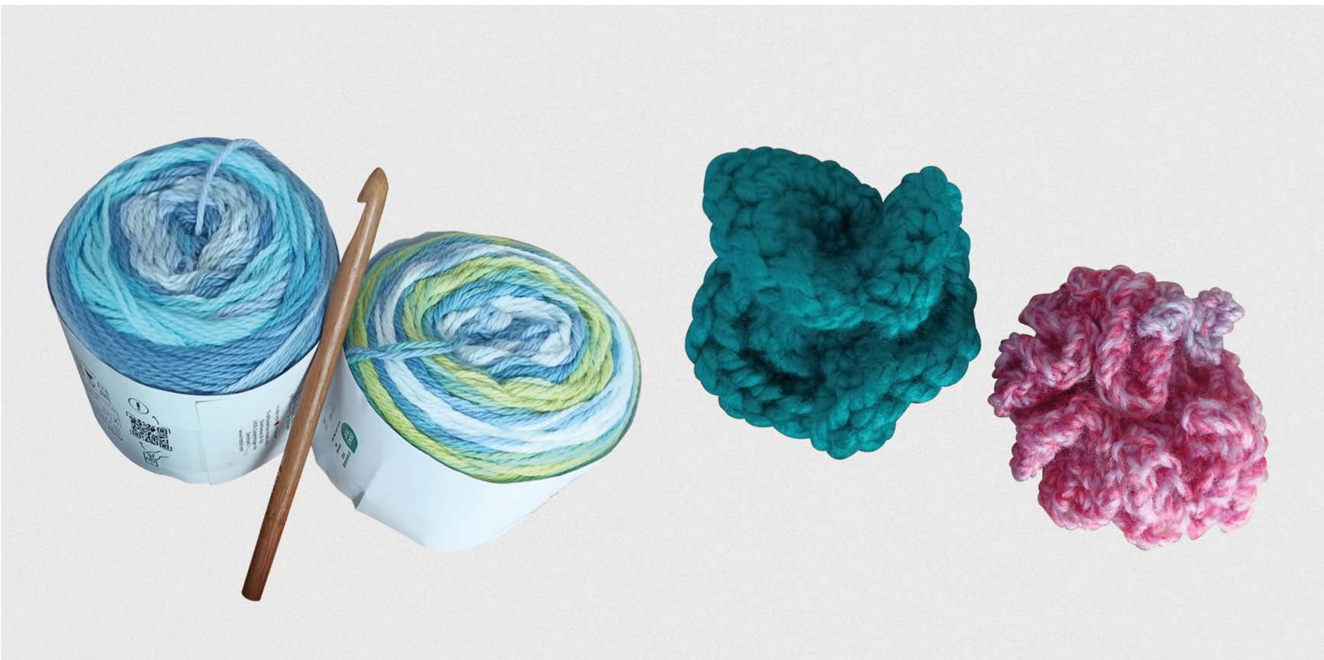
> **The LED changes shade slightly with each degree** increase in temperature

```
import dht
from machine import Pin, PWM
from time import sleep

#sensor = dht.DHT22(Pin(21))
sensor = dht.DHT11(Pin(21))

# Set PWM pins to control R, G, and B LEDs
pwm11 = machine.PWM(machine.Pin(11))
pwm15 = machine.PWM(machine.Pin(15))
pwm12 = machine.PWM(machine.Pin(12))
pwm11.freq(1000)
pwm15.freq(1000)
pwm12.freq(1000)

def set_rgb():
    if temp < 12:
        b = int((12-temp)*6553)
    else:
        b = 0
    if temp < 12:
        g = int(temp*5957)
    elif temp < 26:
        g = int((26-temp)*2621)
    else:
        g = 0
    if temp > 10:
        r = int((temp)*1638)
    else:
        r = 0
    #set LED colour
    pwm11.duty_u16(r)
    pwm15.duty_u16(g)
    pwm12.duty_u16(b)

while True:
    try:
        sleep(2)
        sensor.measure()
        temp = sensor.temperature()
        print('Temperature: %3.1f C' %temp)
    except OSError as e:
        print('Failed to read sensor.')
    set_rgb()
```

We experimented and found that the conditional temperature ranges and PWM values here worked well for us, hitting a reddish shade at 26°C – considered a heatwave in the UK! You may want to alter it to better suit your locality. □

Making mathematical shapes with yarn

Sweater and socks step aside… do something more interesting with your yarn balls



Nicola King

Nicola King is a freelance writer and sub-editor. This subject area fits neatly with her yarn obsession, so finding something to make some shapes with was really not a stretch!

Did you know that the skills of crochet, and indeed knitting, can be very helpful in creating, and therefore accurately visualising, certain shapes? There are a number of mathematical shapes that are enormously difficult to create in any other way, since they are based on non-Euclidean geometry. This is a key reason why a growing number of mathematicians have turned to the skills of crocheting and knitting with yarn as a way of turning those theoretical shapes into something three-dimensional and tangible that you can touch, hold, and basically understand more effectively.

In this article, we will be delving into the fascinating world of hyperbolic planes and Möbius loops… with a twist. This is the intersection of mathematics and handcrafting. It's not a tutorial as such, as we are not going to teach you how to knit or crochet, although we would encourage you to give both these skills a whirl. It's more a discussion of what's possible if you arm yourself with a hook or needles and some yarn, and you have an interest in how the seemingly diverse worlds of mathematics and yarn handicrafts can actually productively cross over. You'll never look at a ball of yarn in the same way again!

CONQUERING CHARACTERISTICS OF YARN

If you try making many simple shapes out of paper or card, you will probably experience some degree of success, but it is undeniable that paper and cardboard are susceptible to tearing or ripping, and are not particularly strong when handled numerous times. The beauty of many yarns in their basic form, and particularly natural wool fibres, is that they are strong and, at the same time, they also possess that magic characteristic: flexibility or elasticity. You can manipulate most yarns to your heart's content, particularly those with a high twist (through twisting, fibres are bound together and create a stronger yarn). When they are crocheted or knitted together from a continuous thread, they often form a sturdy and durable fabric which can be stretched and has a high degree of recovery, even when pulled about a great deal, as a piece of knitting or crochet fabric is made up of elastic, interconnected stitches.

It can also be argued that crocheting or knitting a shape in yarn is potentially a very inexpensive way of replicating any shape, particularly those that are hard to imitate any other way. Certainly, a little time needs to be invested, as we are creating a 3D shape with our own hands, and that is unlikely to be a super-speedy process. However, the basic tools are very low in price, and the end result is likely to be something that will endure.

As mentioned above, some mathematicians are actively using yarn to crochet items to try to understand their field a little better – see the 'Geometric Crochet' box for an overview of Daina Taimina's pioneering work in this area. Take a look, too, at this absolutely stunning creation of over 25,000 stitches which gives insight into how chaos arises – the Lorenz manifold, **hsmag.cc/Lorenz**. The flexibility of crochet enabled this extremely complex shape to be replicated by Dr Hinke Osinga and Professor Bernd Krauskopf. The bottom line is that the crocheting and knitting of mathematical shapes can enable learning in spheres outside of the world of craft. →

Left
Sometimes, all you need is yarn!

> **You'll never look at a ball of yarn in the same way again!**

QUICK TIP

You only need an inexpensive yarn, a crochet hook, and a pattern – delve around to see what you already have in your stash, and get started straight away.

GEOMETRIC CROCHET

A seminal book on this subject is *Crocheting Adventures with Hyperbolic Planes*, (**hsmag.cc/CrochetingAdventures**) written by Daina Taimina, a Latvian mathematician (who is also a retired associate professor of mathematics at Cornell University). She has been a trailblazer in developing a way of modelling hyperbolic geometry with crochet since the late 1990s, holding workshops for university professors where her crocheted models gained much interest.

In 2001, a crocheted hyperbolic plane appeared in the *New Scientist*, and Daina's work then started to receive even greater interest. Her book was first published in 2009 to much acclaim because, until Daina had crocheted her first hyperbolic plane which gave a fantastic tactile insight, no really good physical models of hyperbolic shapes existed (apart from more fragile paper versions), despite the concept of hyperbolic planes being well understood in the world of theoretical mathematics. Once she'd created her own models, Daina used the crocheted shapes when teaching, to better communicate the subject of hyperbolic geometry to her students.

Her book shows the reader how to make mathematics tactile, with a clear focus on hyperbolic planes – she chose crochet as a way of creating such a plane because she feels crochet gives a lot of freedom and she only needed to deal with one stitch at a time (as opposed to knitting, where you need to control many stitches on your needles). You also need very few crocheting skills to create such a plane – just familiarity with how to chain and how to create double crochet stitches (UK terminology), and you'll be away.

Daina teaches you, in her book, how to create a hyperbolic plane, which basically can be achieved if you increase the number of stitches from one row to the next using a constant ratio, but Chapter 1 goes into more detail. If you are already a crocheter, then this is a fun pathway to take on your crochet journey. If you are new to crochet, it really won't take too much time to learn the basics and get underway. If you can crochet and mathematics has always been a favourite subject of yours… well, what are you waiting for?!

Figure 1 This long Möbius strip is crocheted, although you could knit a long rectangle like this as well. A mathematical shape that you can wear!

Figure 2 These planes or surfaces each took about ten minutes to crochet. You could use a cotton yarn for this, and you could then create yourself a very useful wash-cloth or scrubbie whilst, at the same time, wowing your friends and family with your hyperbolic planes

MÖBIUS STRIP

Let's start with a simple mathematical shape – the Möbius strip, also known in fibre arts circles as an 'infinity scarf'. Basically, this is a non-orientable surface with one continuous side and one edge formed by joining the ends of a rectangle after twisting one end 180 degrees. 'Non-orientable' means that, within the shape, it's not possible to consistently distinguish clockwise from counterclockwise turns. This mathematical shape was 'discovered' by Johann Benedict Listing and August Ferdinand Möbius in 1858. However, it obviously existed well before then, and can be seen, for example, as a shape in several Roman mosaics. The discovery of the Möbius strip was also fundamental when it came to the formation of the field of mathematical topology, or the study of geometric properties of a shape that remain unchanged as the shape is deformed or stretched. You can read more on this engaging subject here: **hsmag.cc/Topology**.

The Möbius strip is a very uncomplicated shape, as it's basically one continuous loop. For the knitters and crocheters out there, it makes an attractive scarf if you create a large/long enough rectangle. It also takes very little time to crochet or knit this shape, and the Möbius strip illustrated by **Figure 1** took around half an hour to crochet using quite a thick yarn (the thicker the yarn, obviously the quicker the strip will grow). All this author needed to know, from a crochet point of view, was how to chain and then do treble (UK terminology) crochet stitches back and forth until the piece was as long as required. Having crocheted the rectangle, we then gave one end of the strip a half-twist of 180°, and then brought the two short edges of the strip together, secured with a few stitches.

Interestingly, if you crochet two mirror-image Möbius strips and then sew them together, you can create a representation of a 'Klein bottle'. Felix Klein described this shape back in 1882, as a surface with no distinction between the inside and the outside. Möbius strips are surfaces which have a boundary, but a Klein bottle does not. Read more about this interesting mathematical shape here: **hsmag.cc/KleinInfo**.

HYPERBOLIC PLANES

This author needed to try to understand hyperbolic planes in basic terms before trying to make one, so here we go. If you think about a sphere, the surface curves in on itself and is closed. A hyperbolic plane, however, expands exponentially from any point on its surface, curving away from itself. There are plenty of examples of it in nature – think about the negative curvature on some lettuce leaves, or on some corals or cacti. What's more, it's surprisingly easy to create a hyperbolic plane yourself… by crocheting one. All you need to do is increase at a constant rate throughout the piece.

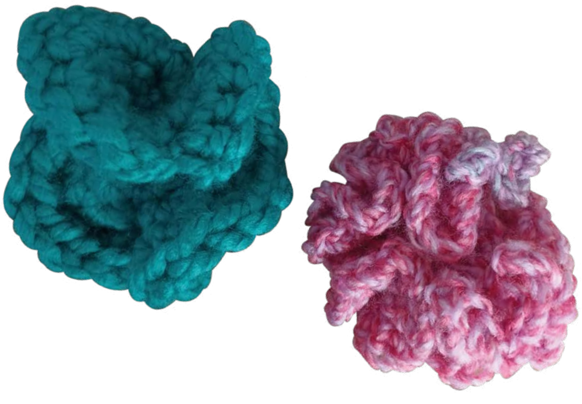
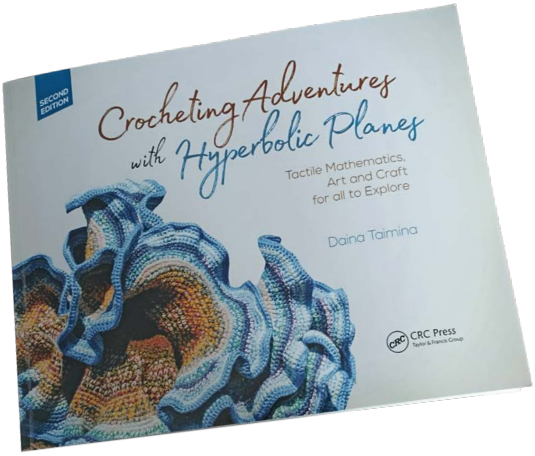
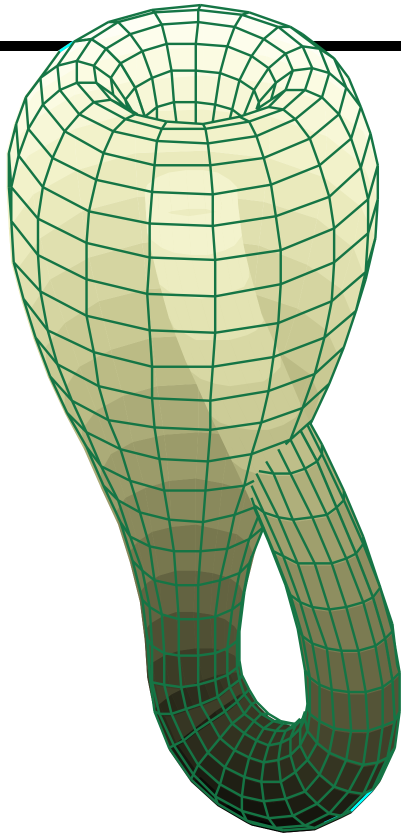


Figure 2 shows the fruits of our first efforts which we hooked up in no time using a thick yarn and an 8mm crochet hook. Basically, for the blue surface, we created six initial stitches and then started the next round by crocheting two stitches into each initial first stitch. For round 3, we then crocheted two stitches into the twelve stitches we had after round 2, and so on. You can really just keep going until you run out of yarn, and we think that hyperbolic crochet can create some amazingly beautiful pieces, especially if you pick some really colourful and contrasting yarns. Each successive round will take longer than the one before it, while early rounds are quick to complete. Learn some basic stitches and have a go! For the pink plane, we increased more rapidly, hence the more 'ruffled' look.





> **We think that hyperbolic crochet can create some** amazingly beautiful pieces

Remember that individual yarns will behave differently, and the size of your piece will depend on yarn used and hook used, as well as rate of stitch increase, so you can experiment with different combinations to see what results you can achieve.

This is a huge subject area, and one that mathematician Daina Taimina covers in glorious detail in her book *Crocheting Adventures with Hyperbolic Planes* (see box for more details). From mathematics, physics, and architecture to biology and medicine, there are many areas where hyperbolic geometry is of interest, and it's a fascinating subject.

WINDING THINGS UP

So, consider crochet and knitting with fresh eyes – these crafts can be used to create some very interesting structures that will stand the test of time, whether you are wearing them as a jaunty Möbius scarf, or teaching a class about mathematical shapes with some very tactile pieces that will simply bring the subject to life. Even in this day and age when machines make so much for us, there is still plenty of room for an artisan to handcraft something from yarn that sheds new light on mathematical shapes and helps people understand and visualise them a little more clearly.

THE CROCHET CORAL REEF

In Chapter 10 of her book, *Crocheting Adventures with Hyperbolic Planes*, Daina Taimina talks about how hyperbolic crochet seemingly went viral after she had published her ideas and her work on the subject. Margaret and Christine Wertheim, who were interested in creating their own hyperbolic crocheted planes, were hugely inspired by Daina's work, and in 2006 the 'Hyperbolic Crochet Coral Reef' project began, and is still running today.

They describe it on their website as an "ever-evolving nature-culture hybrid", and it is truly a beautiful and very colourful piece of work made up of a 'core' collection of crocheted reefs that travel around the world on display, along with the 'satellite' reef program. Their website states that, as of 2023, 50 satellite reefs had been constructed around the world in various galleries, museums, universities, colleges and schools, by a growing community of people interested in the subject areas explored by the work.

The creators of the work believe that making crocheted mathematical structures is a form of 'doing mathematics'. However, it is also a response to climate change at a time when the living reefs are dying from, among other things, plastic pollution and heat. The project talks about time being a framework for the project – time is not on the side of natural reefs, and like the formation of natural corals, these handmade crocheted versions take a lot of time to produce.

An astonishing feat of handmade magnificence that really makes you think, you can read more about this amazing crocheted creation at **crochetcoralreef.org**.

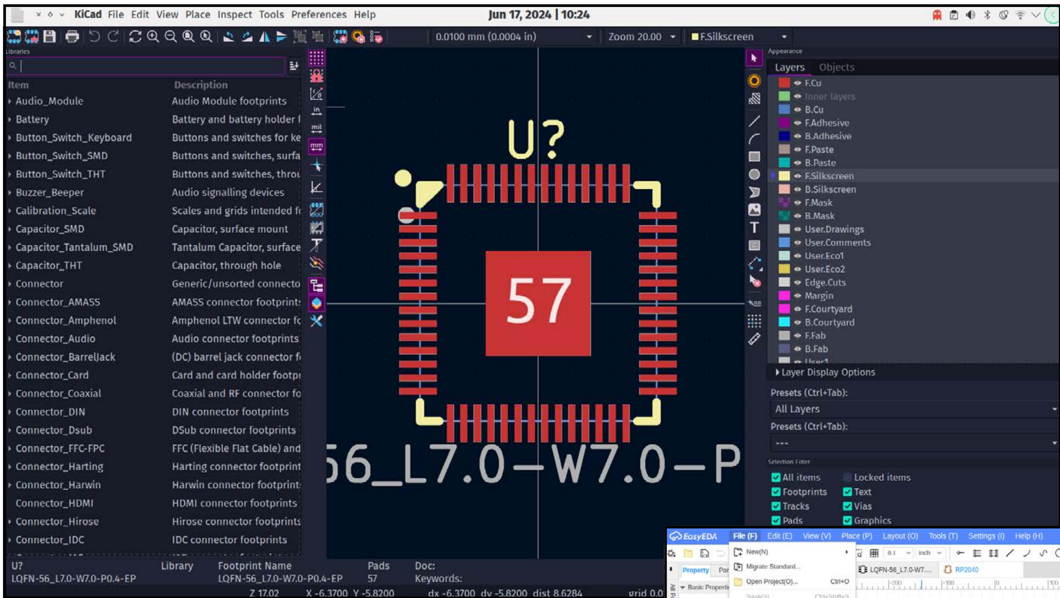
QUICK TIP

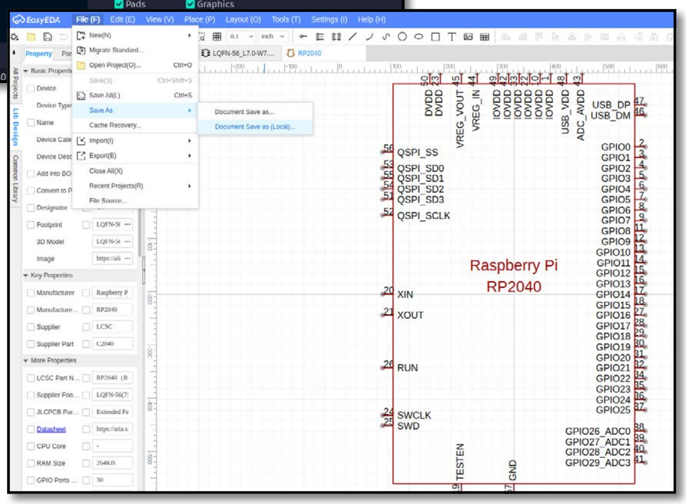
Ravelry is a great source of free patterns. Just search and see what comes up. Here's a free Klein bottle pattern – **hsmag.cc/KleinBottle** – another non-orientable surface.

Above Left
If you are interested in this subject area, this book is a must-have. Daina Taimina even gives you formulae for crocheting a multitude of shapes – the methods are unlike any other crochet pattern you have ever seen!

Above
A representation of a Klein bottle, a surface with no distinction between the inside and the outside

TUTORIAL





Left Importing EasyEDA components is now straightforward in KiCad 8 and doesn't need any external conversion

Figure 1 Using the local Save As option in EasyEDA to download schematic symbols or component footprints

KiCad: tips and tricks

Get the most out of your PCBs

Jo Hinchliffe

Jo Hinchliffe (aka Concretedog) is a constant tinkerer and is passionate about all things DIY space. He loves designing and scratch-building both model and high-power rockets, and releases the designs and components as open-source. He also has a shed full of lathes and milling machines and CNC kit!

Throughout this series, we have occasionally converted EasyEDA footprints into KiCad footprints by downloading the EasyEDA footprint supplied by JLCPCB and using a brilliant online website to perform the conversion. Due to changes in the version of EasyEDA JLCPCB now uses, this route is no longer possible. However, thanks to updates in KiCad at version 8, it's even simpler to import both EasyEDA footprints and EasyEDA schematic symbols.

If we select a component in the JLCPCB parts library and click to view its footprint and schematic details, we can click through into the browser-based EasyEDA as usual. This will open an EasyEDA project with that component loaded in. There are numerous tabs in EasyEDA, and you should be able to find and swap between two tabs: one with the component schematic symbol and one with the component footprint. With the component tab selected and in view, click File > Save As > Document Save as (Local) (**Figure 1**). When clicked, a file with the file type EFOO should download. Whilst we are here, in EasyEDA, swap tabs so you see the schematic component and repeat the same File > Save As > Document Save as (Local) process, and you should download a file with the file type ELIBZ.

Moving to KiCad in the main project view, click to open the Footprint editor. We can then use File > Import > Footprint and navigate to our downloaded EFOO file (**Figure 2**). Select the file and the footprint will be automatically imported. We can then save the footprint to a library or custom library in the usual way using File > Save As.

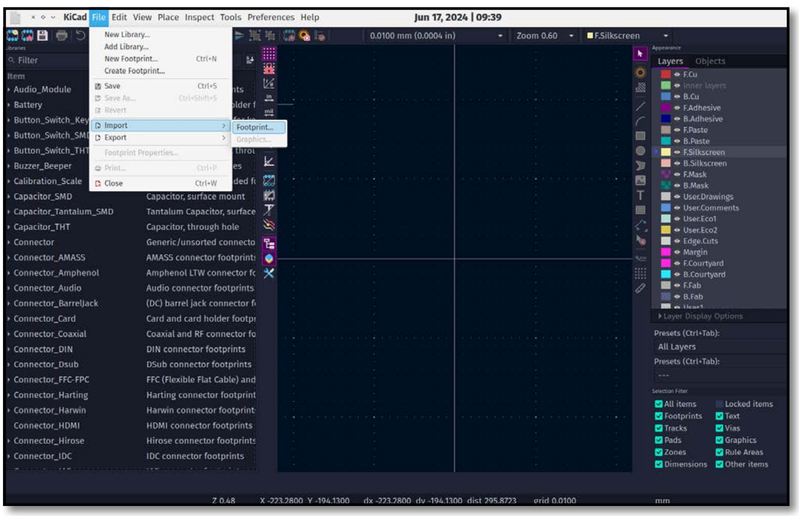
> **A trace is like a wire and can only pass a specific amount of current** before the trace starts to get hot and, in the worst case, melt

It's the same process for schematic symbols. Open the Symbol editor and use the import function to import your downloaded ELIBZ file. It's worth noting that if it's the first time you've opened the Symbol editor or the Footprint editor, you will need to select a working library before being able to import. However, you can, of course, save the imported item to any library you choose.

TRACE CONSIDERATIONS

Throughout this series, we have used different trace widths in KiCad for different sections of our board designs. We've looked at how you actually change the track width in the PCB editor, but we haven't looked at why. Again, this subject can get very complex very quickly. The following is an overview of some of the considerations, but on a sliding scale of hobby maker kit to a heavily engineered medical or space-related device, you see a large increase in complexity of trace design theory. We are showing the lower end of this with some considerations and rules of thumb to promote reasonable practice.

Often we will want to use thinner and smaller traces simply to save space and allow us to rout-out complex chips without the board becoming too big. This sounds obvious, but if you default to a larger trace width, your board will probably be more expensive. PCB fabrication services will usually have the minimum trace size that they can handle listed on their site somewhere. So why don't we always just use the smallest trace size our board maker can supply? Well, obviously a trace is like a wire and can only pass a specific amount of current before the trace starts to get hot and, in the worst case, melt. Most PCB designs will have some parts of the board that are very low current, with other areas having higher current needs. A rule of thumb that's true for RP2040 boards is that traces breaking out GPIO can be pretty thin as the GPIO have an absolute current limit of 50 mA, but more typically, we want to only draw up to 12 mA. Compare this to the power supply lines coming from the USB connector, where these might be drawing up to an amp, and we realise we need different trace widths. →



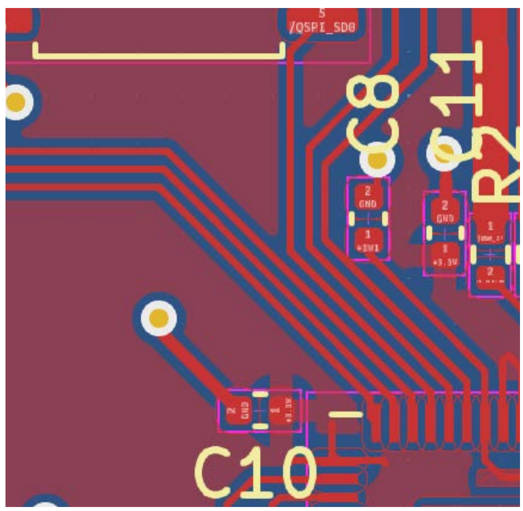


Figure 2 Using the standalone Footprint editor launched from the main project page to import an EasyEDA footprint to a library

Below Often, PCB designs will need a variety of trace widths

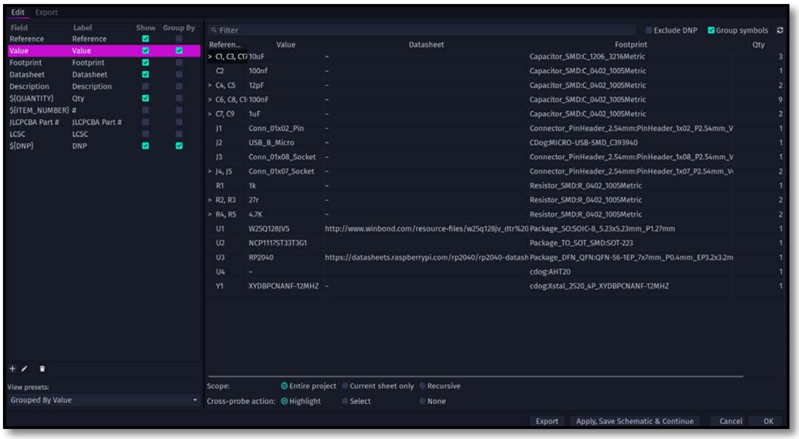


Figure 4
The Edit tab on the new KiCad 8 BOM editor window

Calculating trace widths and current handling can get a little complex, but there are lots of calculators online that can help. One thing we need to know or estimate is the height of a trace on a PCB, as obviously a PCB house that uses more copper in traces to make a taller trace might be able to use thinner trace designs and achieve the same current handling characteristic.

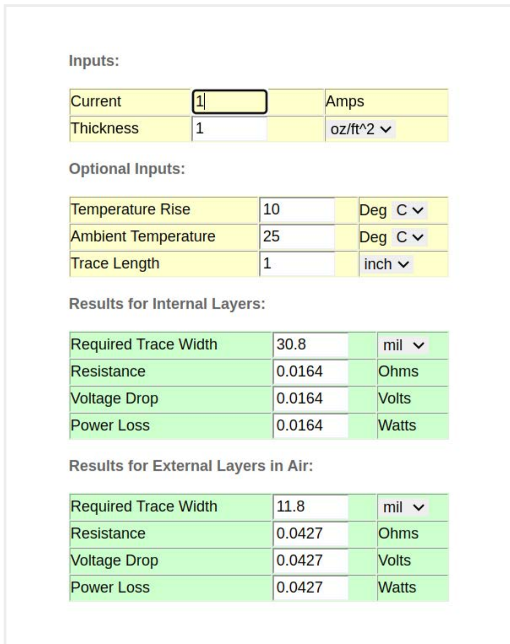
As an example, the standard copper weight for boards from JLCPCB is 1oz. This results in a trace height of just a shade under 1.4 mils where mils are 1/1000th of an inch. It's more common, oddly, for copper weights and traces to be calculated in mils, but don't worry, we can convert it over to millimetres if needed.

> The trace can begin to create magnetic fields and electric charges around the traces

We can use an online calculator to help us work out the required trace width. An excellent calculator can be found at **hsmag.cc/CircuitCalculator**. As a simple example, set the current value to 1 A and the copper thickness to 1oz (**Figure 3**). For a simple value, we can ignore the optional inputs and move straight to reading the results for an internal layer. This says a value of 30.8 mils. If we convert this to millimetres, we get roughly 0.76 mm, so if we use a trace larger than this, for example, 1 mm, we know the trace is overspecified.

Finally on trace widths, there is another factor that we may need to consider: impedance. For PCBs running at lower frequencies, like many microcontroller project boards, and including all the projects in this book, it isn't an issue at all.

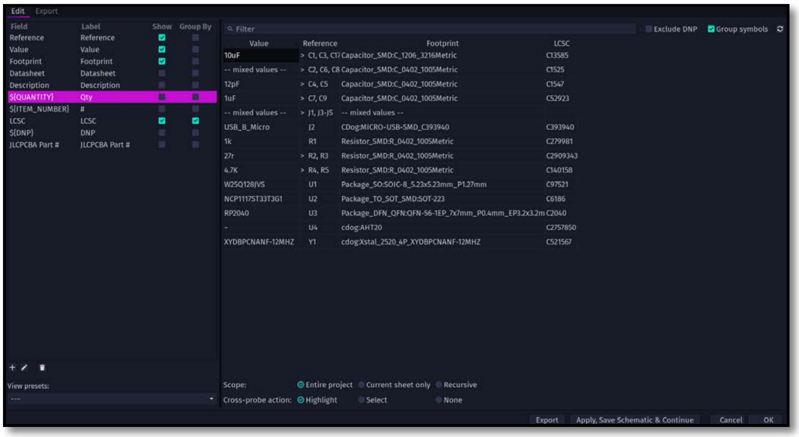
Figure 3
An online trace width calculator



However, as we move to higher frequency designs, it can cause problems where the trace can begin to create magnetic fields and electric charges around the traces, which can interfere with the circuit characteristics. It's a long and involved subject, but primers around the subject and how it can be managed and mitigated can be found online. Here's a good introduction: **hsmag.cc/Impedance**.

SIMPLE BOM

Throughout this series we've used Arturo's script which automates the creation of a bill of materials (BOM) so that the BOM is structured in the correct way for JLCPCB to interpret for the selection and



Left
We've limited the BOM to the correct columns containing the field data we need for our BOM, edited the column positions, and renamed them

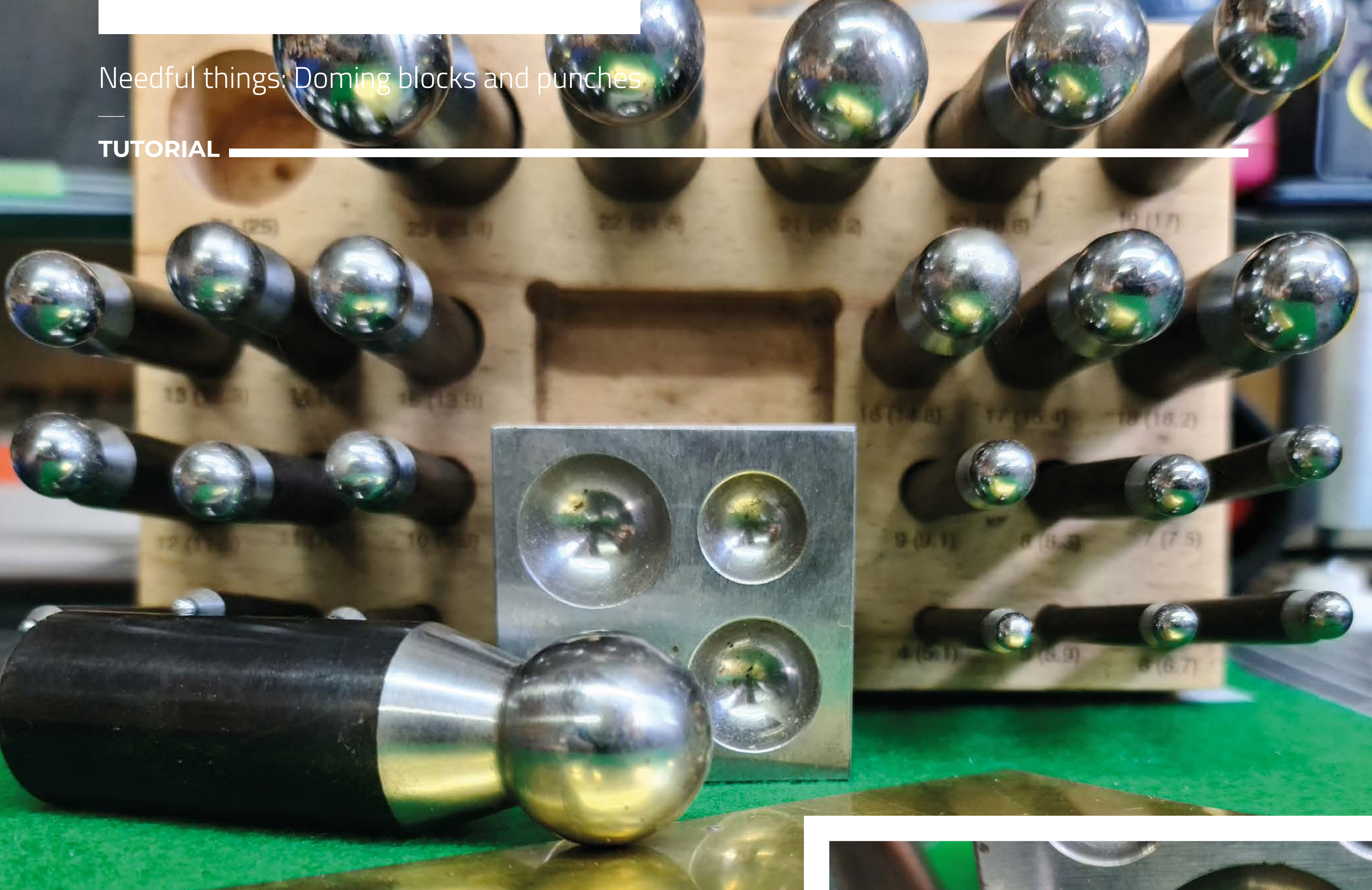
assembly of the correct parts. It's an excellent approach and makes it trivial to produce this information; however, in KiCad 8, there is now a substantial change in the BOM export tools, which makes it much easier to create a custom layout BOM directly from KiCad.

In KiCad, move to the Schematic editor and then click the Generate a Bill of Materials tool icon. In the BOM export window, you need to click the 'Edit' tab on the left-hand side of the window. You should now see something similar to **Figure 4**, with your project components and details listed. On the left-hand side of the BOM editor, you can see a checkbox list of visible fields which we can turn on and off. For a JLCPCB BOM for assembly, we will want four fields for each component. We will need a 'Comment', 'Designator', 'Footprint', and an 'LCSC' for each component we wish to place. In most of the projects in this series, we've added a custom field to each component symbol for the LCSC numbers – notice that this custom field is included in the selectable field. If we uncheck everything from the list apart from 'Value', 'Reference', 'Footprint', and 'LCSC', we should see a preview spreadsheet that looks similar to what we need.

It's likely that your column order doesn't match JLCPCB's specific layout. We can simply click the column title/label and drag it to another position. If the columns are ordered 'Value', 'Reference', 'Footprint', and 'LCSC' from left to right then this matches the JLCPCB BOM examples. Finally, the column field titles don't quite match the JLCPCB requirements. In the left-hand dialog, you can click on the Label column to rename a field title. From left to right, JLCPCB requires a 'Comment', 'Designator', 'Footprint', and an 'LCSC' so that we can make those adjustments. Once everything looks correct, we can click on the Export tab on the left-hand side, set a file name, set the file type to CSV, and then click the Export button. We can also click Apply > Save Schematic > Continue to ensure this BOM format remains in this project.

In case you need it, there are details about the BOM format required by JLCPCB here: **hsmag.cc/JLCPCB_BOM**. Most PCB and assembly services will have similar pages detailing the BOM and other file formats needed.

We hope that you have enjoyed this series of articles. As a long-time user of KiCad, it is astonishing to see how far it has come over the years. We would like to express our heartfelt thanks to all the amazing contributors and developers working on it – you rule! We hope you enjoy exploring, designing, and manufacturing your own PCBs and assemblies and look forward to seeing what you create. □



Needful things: Doming blocks and punches

Move metal the easy way

Dr Andrew Lewis

Dr Andrew Lewis is a specialist fabricator and maker, and is the owner of the Andrew Lewis Workshop.

Jewellery making is a rich source of unusual and beautiful tools. Most of the tools are quite familiar and intuitive to use, but there are other tools that are less easy to identify at first sight. These are tools that serve a very specific purpose that might not be well known outside of the field, or they have a strange name that doesn't immediately explain what they are used for. One of these oddly named tools is the dapping block, which is also (more sensibly) called a doming block. In this article, you'll learn the basics of making domed metal pieces with this beautiful tool.

Some metalworking tools are easy to use – folding tools and shears generally just need the pull of a lever to make a crisp bend or a clean edge, and shaping pliers are simple enough to be intuitive for even the novice user. A dapping block is a more complex tool, and it requires some skill and practice to get good results. Buying a dapping block doesn't mean you'll be able to instantly create perfect metal hemispheres, just as buying expensive brushes doesn't give you the power to paint happy little trees like Bob Ross.

A dapping block usually has a rectangular or cubic shape, with recessed hemispheres of different sizes spread about on the surface of the block.

Left
A dapping block and domed punch set needs some practice to use, but it's extremely effective at doing its job, and is curiously beautiful

Below Left
It's nice to believe that hammering a large domed punch into a metal disc on a dapping block will instantly result in a flat, smooth metal hemisphere. What will actually happen is a creased and jagged failure that looks like an armour-plated bird's nest. This is because you can't just push on the metal and expect it to deform uniformly

Above
It takes a bit of practice, but soon you'll be able to make domes in a range of sizes

Left
A series of small adjustments around the surface you are bending is better than trying to make one big bend from a single point. The big punches are more effective when the piece is already close to the final shape

> "**Keep increasing the punch size until you get to** the biggest one that you can manage"

You can use these recesses in combination with a set of domed punches to form sheet metal or shape rings. Although a dapping block is tiny compared to a blacksmithing post or anvil, the same rules of metalworking apply. When you hit with the punch or hammer, you are going to be moving metal from one place to another. Parts of the sheet will get thicker, while others will become thinner.

To get a better result, start with a small punch, and work around the edges of the metal, punching them into a gentle curve. If you see any creases starting to form, chase them out to the edge using the punch. As the metal starts to get closer to a hemispherical shape, move up to larger punches and keep chasing around the edges to bend them without creasing the metal. Keep increasing the punch size until you get to the biggest one that you can manage, then smooth away any remaining imperfections using the large punch. You can also start in a larger recessed dome, and gradually work down to a smaller one as you bash the metal into shape. This may help to get the general shape, but be careful not to thin out the centre sections of the disc, as you will end up with a creased and thickened rim around the edge.

Don't be tempted to go too quickly, and don't position the punch so that only part of the striking surface is covered. This is important because, although the doming punches are often hard, they are not indestructible. A piece of metal positioned part-way across the punch could result in a hard line being transferred to the punch itself. If this happens, every strike of the punch will transfer the hard line mark onto the workpiece, which is extremely frustrating if you don't notice it in time.

Tin Can Allies

Reuse before you recycle and help the environment

Above
Before 3D printers and laser cutting was so accessible, it wasn't unusual to see home electronics projects put into tin cans, biscuit tins, and other recycled containers

Dr Andrew Lewis

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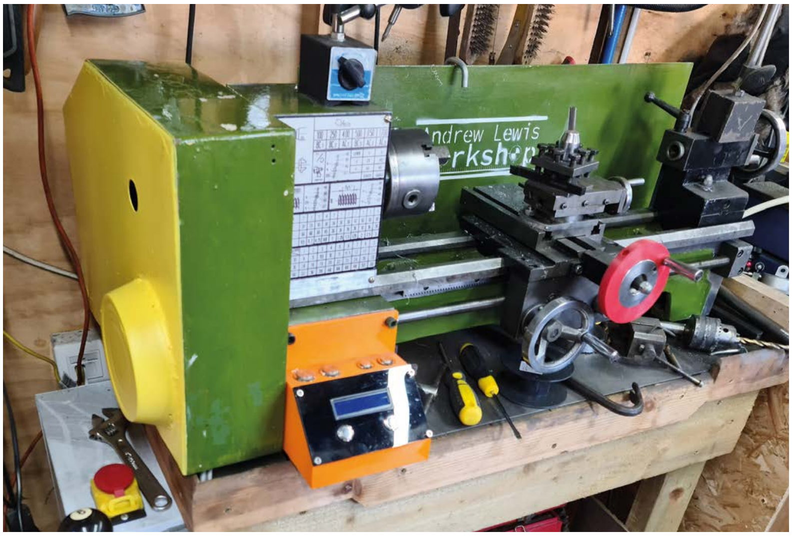
The mantra of Repair, Reuse, Recycle is burned into the mind of most environmentally conscious people. We all know that the throwaway society is unsustainable, and we can do our part by keeping things out of landfill. There's a problem with this mantra, though. The first word of it pushes our thinking towards things we have that can be repaired, like clothes or high-value electronic items that we all agree deserve to be shown some care. It doesn't feel like we can move backwards and repurpose things that are supposed to be thrown away.

We take common household items for granted, and dispose of them without a second thought because they are designed to be recycled once they've been used once. Obviously, nobody is going to try and repair a tin can and reseal the top, because that's what reusable jars are for. But, that doesn't mean we should march over to the recycle bin with our tin cans, because there is a whole world of useful projects that need the resources a discarded can provides.

SHARP EDGES

It's very easy to injure yourself on a piece of sheet metal, and that includes tin cans. Some can-openers leave ragged edges to the metal, and corned beef tins with a little twistkey regularly cause people to visit their local hospital. Wear leather gloves if you're working with sharp edges, and remember to double over your edges if you're making something from sheet metal.



Left The indent for the motor on the side of this lathe is actually a steak-and-kidney pie tin that's been brazed into place on the case of the motor. There's no shame in reusing the tin rather than recycling it directly, and using the ready-made shape was a lot easier than making one from scratch

Below To make a basic power pack you'll need a 4S battery controller, four 18650 batteries, a panel-mount USB socket with built-in power supply, a panel-mount cigar-lighter socket, a panel-mount voltage meter, a panel-mount fuse-holder, a power switch, and a panel-mount 2.5 mm power socket

QUICK TIP

Larger cans will fit more batteries. You could always ask a local restaurant if they have any empty catering tins you could take away. They have to pay to get their empty tins disposed of, so you'll hopefully be able to get something chunky enough to hold a lot of batteries.

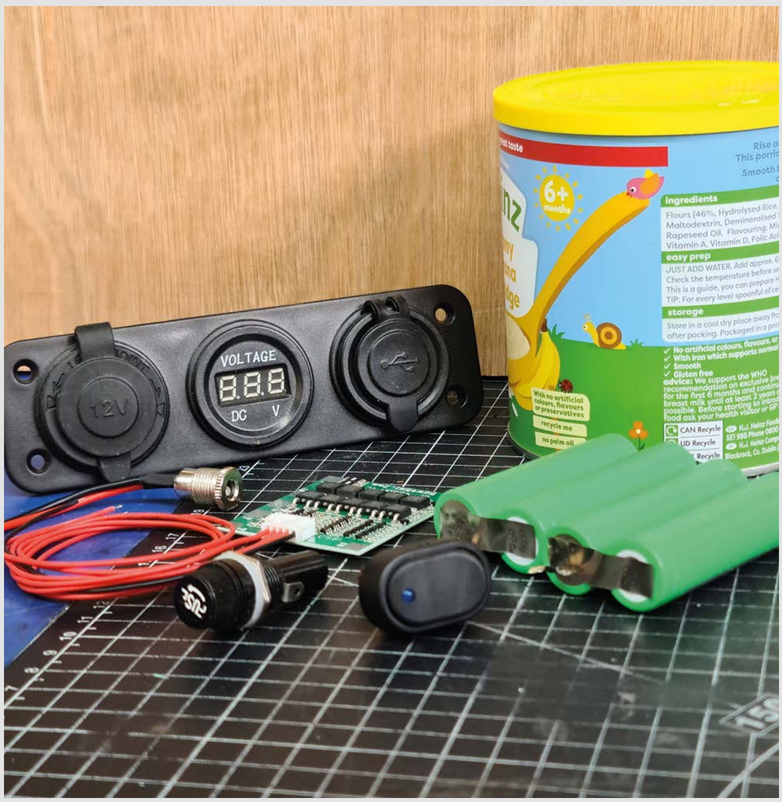
POWER PACK

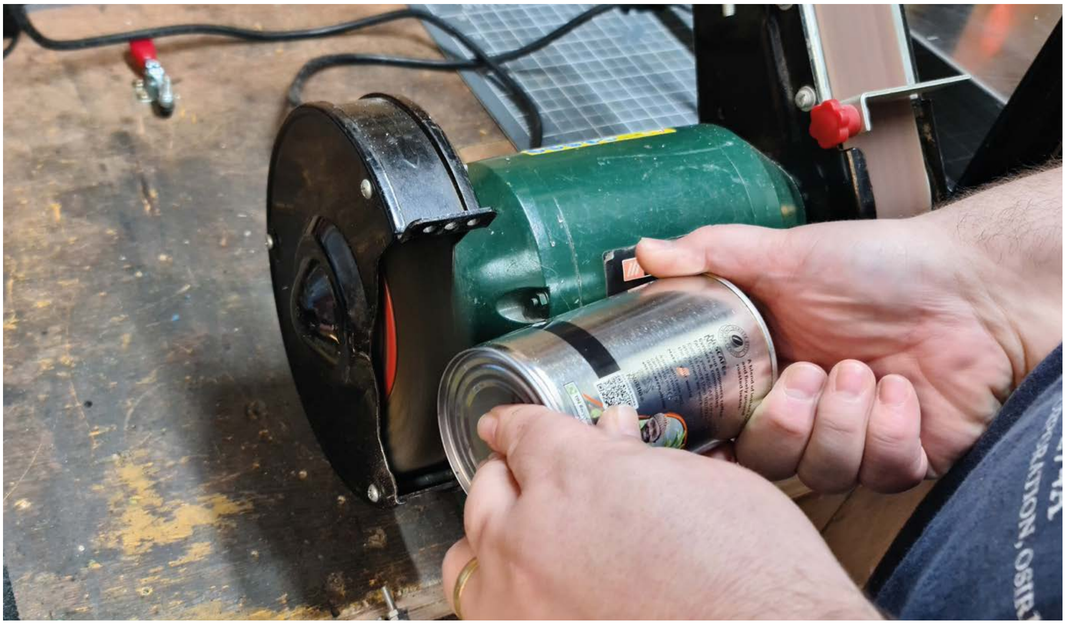
A portable power pack is a useful tool to have, but most of the commercial offerings are USB only, so don't give you access to the full power of the battery pack. With a few panel-mount fittings, some batteries, and a tin can, you can make a rugged power pack to suit your own specifications.

18650 batteries need a controller to make sure that they charge and discharge safely. You must use a battery welder to connect the individual cells to the controller and make a battery pack. Soldering 18650 batteries directly will damage them permanently.

Once you have a soldered battery pack, it's very easy to connect the individual panel-mount sockets and indicators to the pack via a fuse and a power switch. Be aware that 18650 batteries can dump an enormous amount of power at once, so installing a fuse is absolutely necessary and cannot be skipped. The fuse should be the first component connected to the battery pack so that every other item connects through it.

The battery controller will make sure that the battery pack charges correctly, provided that you supply sufficient voltage and current. The fully charged voltage for a 4S pack is about 16.8 V, but charging the batteries to 100% capacity will shorten their lifespan. Providing an input charge voltage of around 16.3 V should be sufficient to charge the batteries safely. You can provide this voltage from a suitably set DC buck converter. The 2.5 mm socket provides the input power point, but remember that the power socket will be wired after the power switch – so the pack won't charge unless the power switch is on.





QUICK TIP

It's best to use the laser microscope in a darkened room so that the laser projection isn't bleached out by natural light.

Right The laser microscope can be addictive, and isn't just limited to pond water. Pretty much any translucent liquid can be examined

QUICK TIP

If you enlarge the hole for the laser too much, just use some hot glue to hold the laser in place.

Why are tin cans so useful? For one thing, they're a ready-made container, and they tend to come in predictable sizes. Different cans and jars can be connected together because they are designed to hold a certain amount of food, and fit in a relatively standardised industry landscape. You can glue them, paint them, and cut, drill or punch them with household tools.

As a source of metal, they can provide a range of smooth or textured sheet in a variety of different thicknesses and even different materials. For shims, compression gaskets, and small tinsmithing projects, they are essentially a free source of material that for some reason we completely ignore and toss into the recycling bin without a second thought as we wander off towards the model shop and buy some metal sheeting from the K&S stand. We need to accept and normalise that just because something is designed to be recycled, that doesn't mean it can't be reused or repurposed.

What sort of projects really benefit from a tin can? The obvious answers like 'paint a bean tin to make a flower pot/desk organiser' or 'put a magnet on the bottom of a tuna can to make a magnetic parts tray' are functional ideas, but there's so much more you can accomplish with a bit more thought. Essentially, anything that goes into a project box could go into a tin can, so let's have a look at a couple of fun ideas that can be put together in just a few hours. If it turns out you don't like these projects, you can still take them apart and recycle them. □

Left
Some tin cans have designs printed directly onto the metal, rather than a paper label. It's surprising how resilient the printing can be. A wire wheel or some coarse wire wool and a strong solvent are probably the easiest ways to clean off the design. Alternatively, just paint directly over the top, or use a vinyl wrap

Below Right
The only things you need to make a laser microscope are a tin can with one open end, a laser emitter, a battery pack, a blunt needle in its protective sheath, a syringe, and some hot glue

> **As a source of metal, they** can provide a range of smooth or textured sheet in a variety of different thicknesses

QUICK TIP

Lasers are dangerous. Only use a low-powered class 1 laser for this project. Never look directly into the end of the laser emitter, and never point the laser at a surface that might reflect the laser back at you or anyone else.

LASER MICROSCOPE

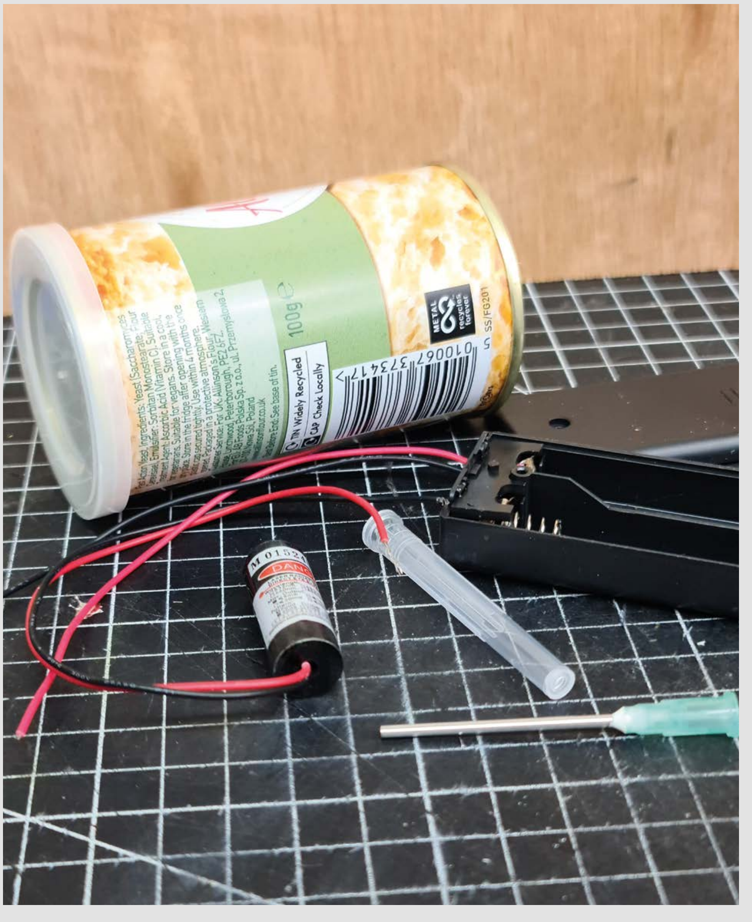
A laser microscope is a great project for people who want to explore the tiniest parts of the world around us. It's a quick project that you can make in about half an hour. A laser microscope works by shining a laser beam into a droplet of water that's suspended from a fine needle or dropper of some sort. The droplet acts as a lens, scattering the light from the laser so that a silhouette of anything in the water droplet is projected onto the nearest wall or perpendicular surface.

Begin by drilling a hole in the bottom of your tin can, as close to dead centre as you can. The hole should be the same diameter as your laser emitter, and ideally you want it to be a push fit so that the can holds the laser in place.

Align the laser so that it is parallel with the sides of the tin can, and then make a small hole in the side of the can along the same line as the laser emitter (along the centre line of the can). This hole should be the same diameter as the protective sheath that the needle fits into. Cut 10 mm off the closed end of the sheath so that the needle pokes out of the bottom when the sheath is in place.

Push the sheath into the hole in the can, and align it so that the end of the needle is just above the path of the laser beam. You want the resting position of the needle to be set so that a droplet of water suspended at the end of the needle will be directly in the path of the laser.

Connect a battery pack with an on/off switch to your laser emitter, and put some batteries in. Glue the can on top of the battery pack, and go hunting for some dirty water with your syringe. Draw a small sample of the water into the syringe, and then insert it into the sheath that you've fitted into the can. Point the laser microscope at a plain white surface, push the syringe slightly so that a droplet forms at the end of the needle, and turn on the laser. If everything is aligned correctly, you should see an eerie phantasmagoria projected onto the wall, with tiny creatures floating in and out of focus.



Getting jiggy with it

Advance your workshop skills with custom jigs

Dr Andrew Lewis

Dr Andrew Lewis is a specialist fabricator and maker, and is the owner of the Andrew Lewis Workshop.

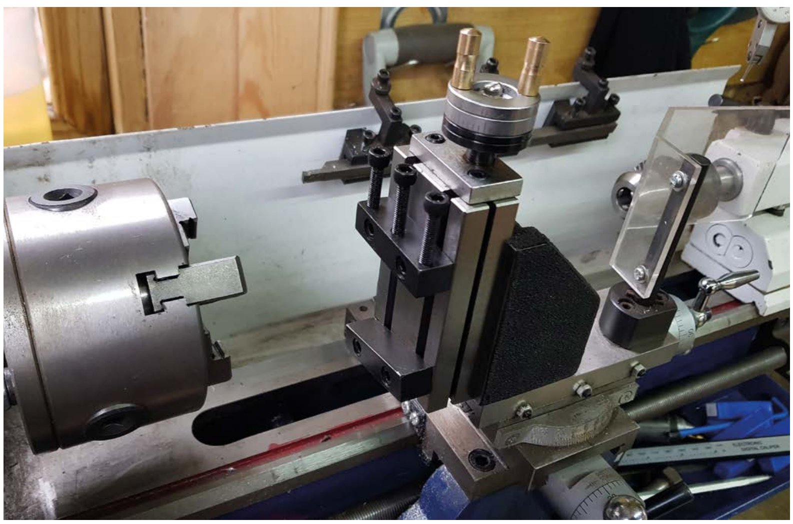
Looking through a hardware store catalogue, you'll find all sorts of commercially made jigs. Jointing jigs, pocket jigs, and routing templates are used by tradespeople to complete common tasks because time is money, and jigs typically save time. They can also reduce the chance of making a mistake while you're working with a tool, which can cut down on waste materials. If you're a hobbyist used to working on one-off projects or an independent maker working on small batches, you might dismiss the idea of a jig as 'something professionals use', and be happy to push through the project relying on the old mantra of 'measure twice, cut once'. This is sometimes a mistake, because jigs are one of the most important tools you have at your disposal in the workshop, and in this article you'll find out why.

MEASURE NONE, CUT HUNDREDS

Creating and using jigs while you are working can be one of the most satisfying and productive changes that you can implement if you're making the transition from amateur to professional maker. When you create a jig, you are demonstrating that you're thinking about the process of making, about improving that process, and about ways to make your job easier, cheaper, or more accurately than you can with existing methods.

To be perfectly clear, being a 'professional maker' doesn't mean that you always need to use a jig. The jig police are not real and they cannot hurt you. You will not be shunned by the community for failure to use a jig. There are times when it's appropriate to use a jig, and times when it doesn't really make a difference. The key is that you understand that doing the extra work necessary to create a jig can have benefits.

Left
If you feel like you're spending more time setting up your machines than creating actual products, it might be time to step back and think about designing some jigs. While a jig might take a little extra time to develop at the outset, it can save hours of work in the future. This simple jig holds six wooden coasters in place for sublimation printing, and significantly reduces the time and material cost required to create a batch of coasters



Above
This rotary jig and Z axis jig are good examples of how jigs can add functionality to a machine as well as just enhance existing processes. This is something that often gets overlooked when people talk about using jigs – they can improve your workflow by adding features without significantly increasing costs. The rotary jig allows you to laser-etch onto a cylindrical object, instead of flat surfaces. The Z axis jig lets you perform milling operations on a lathe, which can be useful if you have limited space or funds for a dedicated milling machine

Those benefits may manifest themselves in terms of future time saved, by increasing the accuracy or finish quality of your project, or by adding a safety barrier to a task that might go wrong and ruin a unique or expensive part. As a hypothetical example, drilling a hole halfway through the bottom of a boat that's in the middle of the ocean is theoretically possible using just a drill and a bit of masking tape to mark the depth that you need to stop drilling. It's possible to do this, but it's obviously a terrible idea to do it this way. Using a short drill bit in a jig that stops the drill from progressing too far into the bottom of the boat is a much safer option. Cutting a curve through a piece of expensive plastic is theoretically possible with a jigsaw and a pencil mark. It's much easier and more accurate to use a router with a jig to control the path of the blade. In these situations, using a jig is obviously a good idea. →

Right This tile jig can be reused, because it has a solid surface to butt against on the top and left of the MDF. If you don't have a solid surface, you can create a temporary fixed position by either gluing the MDF into place, or gluing solid edges into place that you can butt the template against

However, in a situation where you're making a one-off project, an elaborate jig can be more expensive and time-consuming than the project needs. Let's ditch the hypothetical examples and take a look at some real-world examples of how jigs can be used to improve your workshop life.

Most makers are familiar with laser cutters, and how they can cut or engrave very fine details into a material. However, the bed of a laser cutter is often just a meshed surface, and while this is fine for cutting out shapes from a sheet of stock material, positioning items precisely on the bed of the machine can be very tricky. If you need to engrave or cut something in a specific place, you need to create some sort of jig to hold your work in place. Some laser cutters have a camera that lets you see the bed of the machine and adjust the position of designs in software so that they are engraved in the right place on the target object. You can also use tape to indicate the home corner of the laser cutter and calculate the precise positioning from there. Neither of these solutions are particularly good in practice.

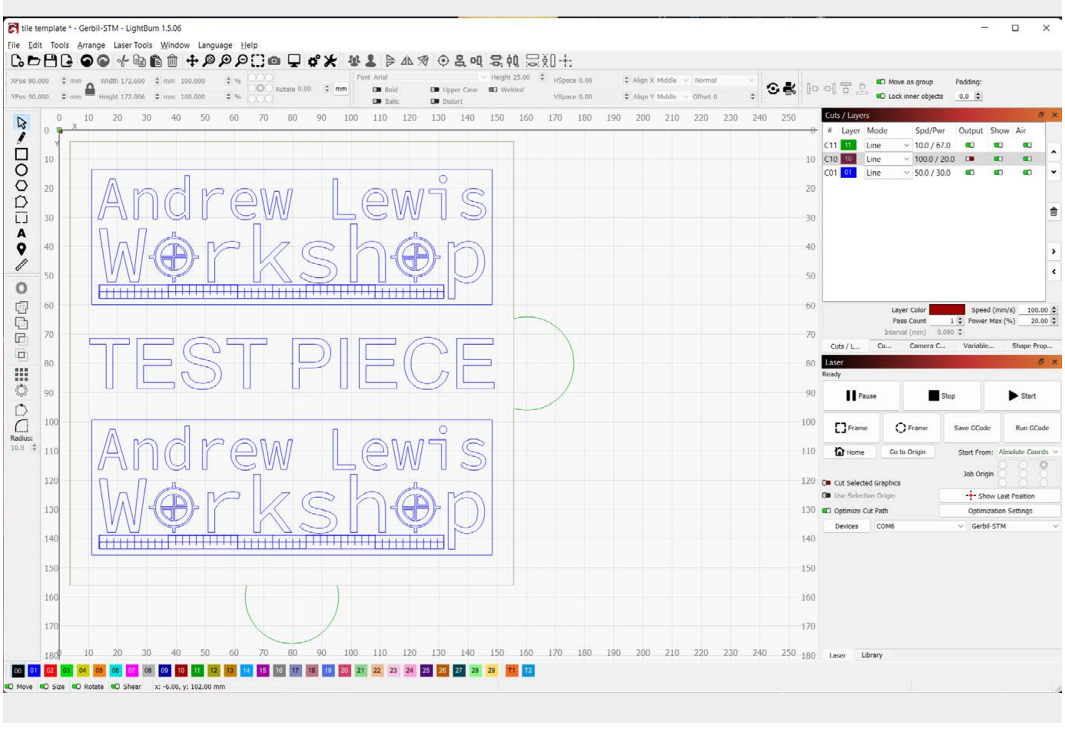
Firstly, in the case of a camera overlay, if you are engraving several identical objects you will need to adjust your design in software to align with each of the objects. The camera viewing the bed is not necessarily 100 percent accurate when it transforms the absolute position of the object from the bed of the machine to the monitor, giving an unexpected margin of error. Taping the corner of the bed and measuring out from there is problematic because the observed position of the tape will change slightly depending on the position of your head relative to the object you're placing, and it takes time to make fiddly measurements and adjust objects so that they line up properly. In some cases 'it looks straight therefore it's straight' just isn't a good enough methodology.

In a case like this, generating a disposable or reusable jig is an excellent way to tackle the problem. Let's assume that you have a series of ceramic tiles that you want to engrave with a repeating pattern. You want these patterns to align accurately with the edges of the tile. Start by measuring your tile, and then grab a piece of thin MDF sheet. MDF sheet is cheap and easy to cut with the laser, and you're going to use it to create a temporary jig. Glue the sheet to the bed of your laser cutter using a few dots of hot glue at the corners. Don't go crazy with the glue; think of what you're doing as tack welding with a glue stick. You don't need to be accurate with this, but do make sure that the board is flat against the bed of the machine, and that the edges of the board roughly align with the X/Y axis of the machine.

Use your laser cutter's software to create a new file with a cutting path somewhere on the area of the MDF sheet. The cutting path should match the measured size of the tile you want to engrave. Lock this path in position, and add an 'out-dent' at one edge so that you can get your fingers in to insert and remove the tile from the space you are going to cut out. Save the file.

Home the laser cutter, then cut the path in the MDF and remove the tile-shaped piece of MDF from the middle of the jig. The remaining MDF is glued into place, and if your laser is focused properly, you should now have a way of positioning the tile on the bed of the machine with less than 1 mm accuracy. It's cheap and easy to remove when the job is done. All that remains is to add your engraving pattern in your laser cutter software and to disable the cutting path. Save the file again, and engrave tiles to your heart's content. Once you've finished processing the batch, you can pop off the hot glue and remove the template.

In this example, we used a tile to demonstrate how to create a disposable jig for a tile – but you can use this technique to position any shape or size of object, engraving multiple items at once if you have enough space on your machine. If you are familiar with LightBurn software, you probably won't be too surprised to discover that its community resources (and also YouTube) have numerous links to premade jig templates for common products like dog tags, leather key rings, and pendants. The tutorials may implement the jig with a different method from the technique described here, but the templates can still be used in the same way if you wish. →



Left
This LightBurn template has multiple layers that can be used to create a jig, and to engrave the surface of the tile. You can see that there are semi-circular cutouts along two of the edges to make it easier to replace the tile between engravings

QUICK TIP

If you can position the MDF against the edges of the machine in a repeatable way using fixed points, you can reuse the jig multiple times. If not, you'll need to throw it away and cut a new jig after it's been removed from the bed.

Above The jig for this coaster was too thick, so the heated press couldn't effectively apply pressure across the whole surface. You'll notice that the black print on the right side of the coaster is pale and uneven because the contact with the transfer paper was poor

> **This sort of reusable jig does** several things at the same

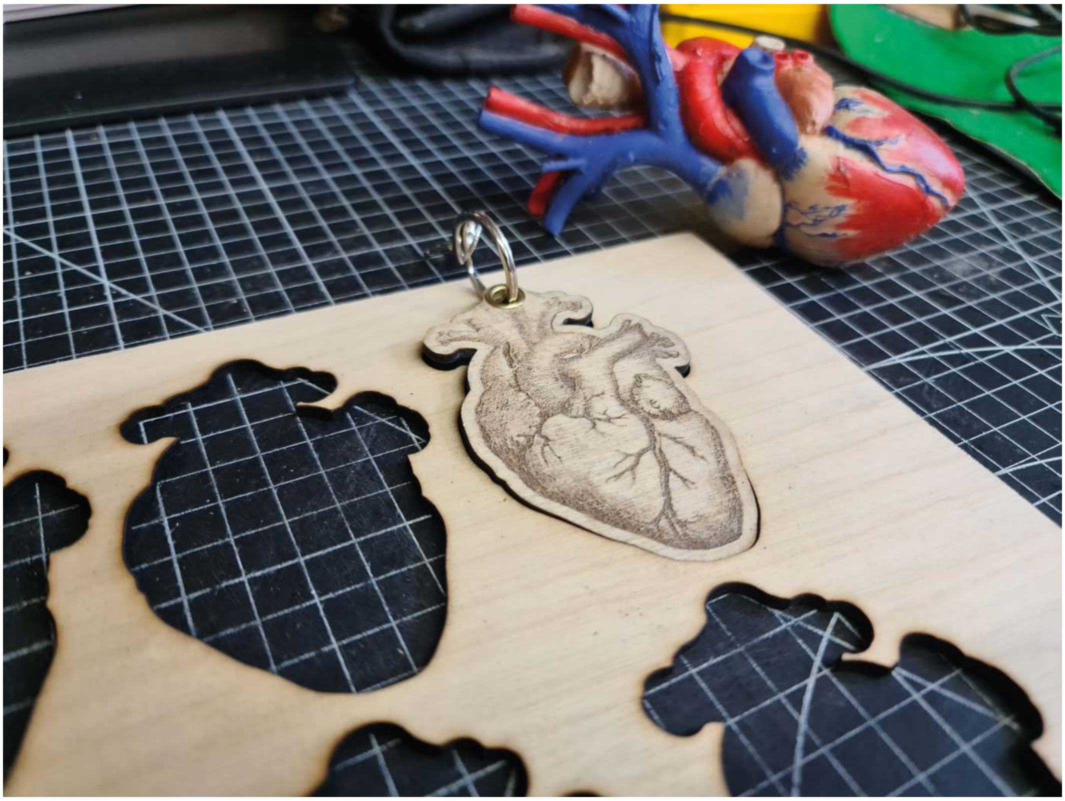
If you do have access to good laser software (like LightBurn) and you want to create a very accurate template, you can modify the kerf-offset settings to account for the thickness of the laser beam when cutting. By shifting the laser beam inside the shape you're cutting out, you can create a more exact-sized cutout. This might be useful if you are etching or cutting the solder mask on a PCB to expose traces, but for simple etching projects like key rings or business cards, this isn't necessary.

You might also use a jig to save materials or make it faster to create multiple items at once. Let's start out by thinking about sublimation printing some drinks mats or coasters. The basic process for sublimation printing is to print out the design in reverse using special ink and paper, and apply it to a specially prepared blank coaster with a heated press. This means lining up the coaster with the paper and holding the paper in place while the press is down. For a single coaster this is fine, but it gets fiddly and time-consuming when you're making multiple coasters. You need to print the designs, cut them to shape and tape them onto the coasters, then press them, let them cool, and remove all of the pieces of tape.

With a well-designed jig, you can hold multiple coasters in place at the same time, cutting down on waste. Beginning with another blank sheet of MDF, measure your coasters. The MDF should ideally be about 1 mm thinner than your coasters are. Put the MDF into a laser cutter if you have access to one. You could use a fretsaw or another cutting tool if you don't have a laser cutter. You don't need to glue the sheet down this time. Depending on the size of your coasters, you'll probably have room for between four and six coasters on your sheet of MDF. Cut coaster-shaped holes in the sheet so that you have a few millimetres of border between each hole, and a few millimetres of space around the edge of the sheet. You want your jig to be smaller than the sheet of paper you'll be printing your designs on so that it's easy to fold the edges of the sublimation paper around the jig.

You're going to be using this MDF in a hot press, so make sure it's dry before you cut it by pressing it on both sides for a few minutes and then letting it rest. If it warps, it's still got some moisture in and needs more time to level out. Re-pressing may help if the MDF doesn't go flat after a while.

Print your designs onto the paper so that they line up with the holes in the MDF sheet and leave a print bleed around the edge. The print bleed is used to make sure any minor changes in the position of the coasters on the jig won't result in an unprinted edge. In other words, print the coaster designs slightly larger than the coasters actually are, and increase the border around the edge. This will mean everything will still look good if the coasters are slightly different sizes or the paper



moves slightly during the pressing process. This sort of reusable jig does several things at the same time. It lets you treat several coasters as one object, which is more convenient to move around. It also means that you can eliminate the 'cutting out' step from your printing process, so instead of cutting out six individual designs, you simply print your six designs on a single sheet, align the sheet with the jig by eye, insert the blank coasters, and then fold the paper into place around the jig. Another benefit of this jig is that you can hold the paper for six coasters in place using two small pieces of tape, instead of the twelve pieces of tape that you need to produce the coasters individually. That saves money and reduces the amount of waste produced during the printing process.

While these examples show how you can create custom jigs yourself, there are plenty of pre-existing jigs out there that can be used to speed up your workshop and improve the quality of your work. Some jigs, like the shirt folding jig, are designed with the intention of regularising a high-level task (in this case, the name of the jig should give away the intended purpose) and make it easier to complete without experience. Other jigs serve a more fundamental purpose, like a drilling jig, which is created to improve the precision of drilling operations by holding the drill bit at 90 degrees to the surface being drilled. Tapping jigs and pocket hole jigs serve a similar purpose.

If you have access to a 3D printer, there's a huge range of jigs that you can create to make any number of workshop tasks less onerous. Even a cursory search will bring up printable jigs for common operations like tapping, indexing, tool-sharpening, circle-cutting, dowelling, edge-rounding, and shaping. Many other jigs can be downloaded for specialist tasks like guitar tuner drilling and aligning rocket fins. □

Above Left
There are times when you're working with a laser cutter that you accidentally create a jig during the cutting process. The waste product from your project ends up with a perfect cutout shape of the parts, and this can be used as a jig or mask for finishing processes like painting or sublimation. You can see that waste cut from these heart key rings makes a perfect jig for holding the blanks while they are sanded and sprayed

Part 02

CDP Studio: Control a robot arm with a Wii Remote

Use CDP Studio with a Nintendo Wii controller to manipulate a Raspberry Pi-based robot arm

MAKER

Phil King

Long-time contributor to *The MagPi*, Phil is a freelance writer and editor with a focus on technology.

@philkingeditor

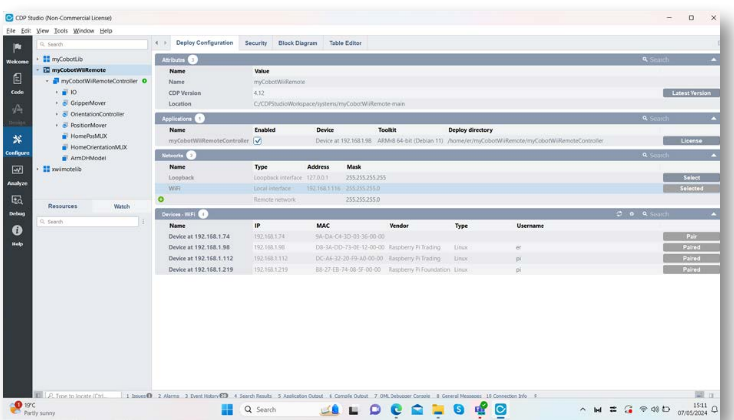
Last issue, we showed you how to use the CDP Studio software development tool and its Kinematics framework to record movements for a Raspberry Pi-based robotic arm – the myCobot 280 Pi from Elephant Robotics – that could then be played back to perform a 'pick and place' routine using the Adaptive Gripper add-on. This time we'll be using the same setup, but controlling the arm manually using a Nintendo Wii Remote and Nunchuk.

If you don't have the robot arm, you can still run the project by deploying it to a Raspberry Pi and viewing the movements in the on-screen arm visualiser.

01 Install the software

If you haven't already done it for the previous tutorial, you'll need to install CDP Studio. On your PC, visit **cdpstudio.com/getstarted** and download the free non-commercial version for Windows or Linux. During installation, select the 'ARMv8 64-bit (Debian 11)' component under CDP Studio 4.12, along with the one already ticked for your host PC. You will then be able to deploy projects to the myCobot 280 Pi arm, which uses a 64-bit version of Ubuntu.

If you already have CDP Studio installed, make sure it's updated to the latest version (Help > Check For Updates). Then go to Help > Package Manager and select 'Add or remove CDP versions' to add the ARMv8 64-bit (Debian 11) component if not already added.



You need to pair CDP Studio with the arm's Raspberry Pi over the Wi-Fi network to deploy the project

02 Download the project

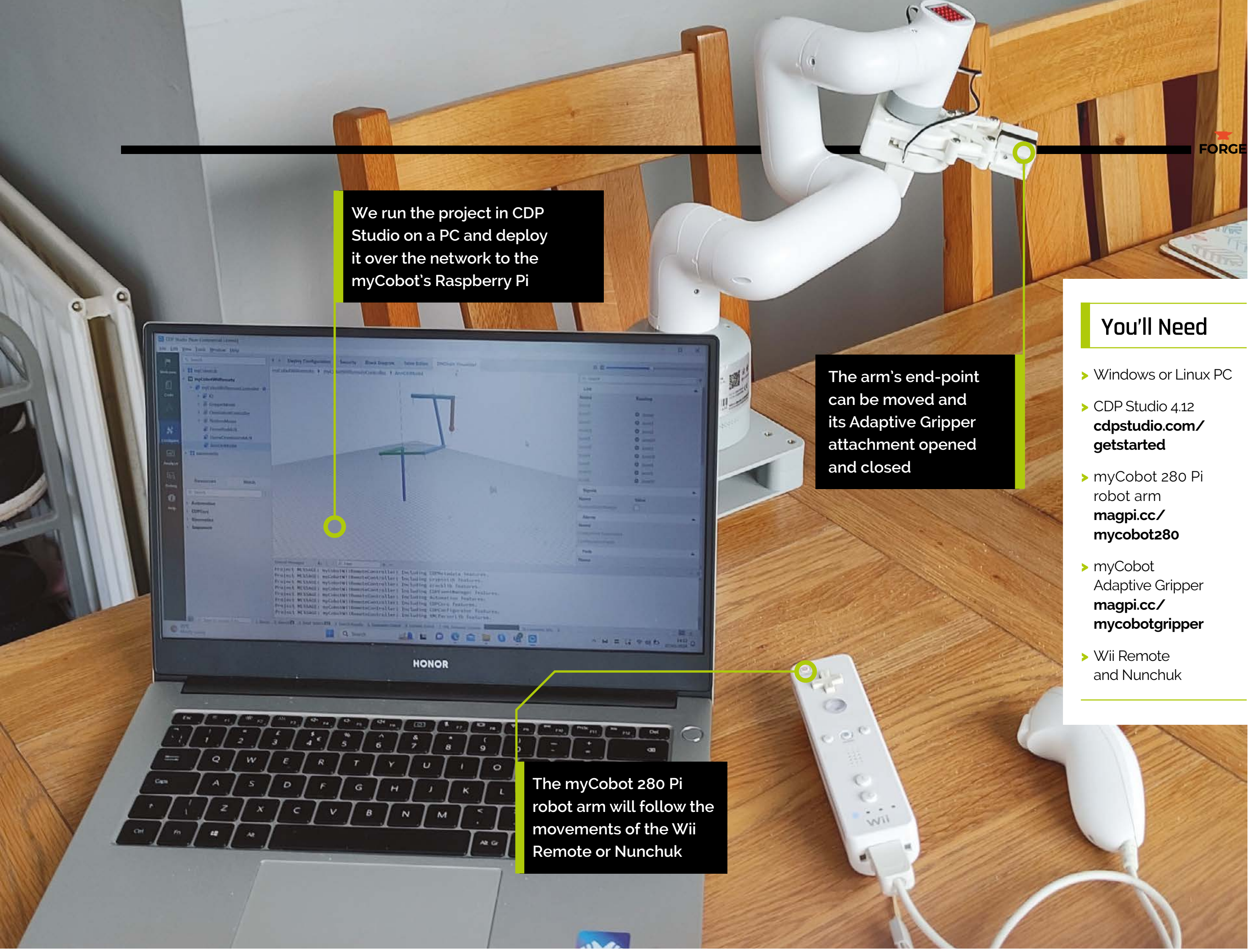
This is a complex project that would be time-consuming to build from scratch, so we'll download it from CDP Studio's GitHub repo. Go to **magpi.cc/mycobotwiiremote**, click the green Code button, and select 'Download ZIP'. Unzip the file on your PC. Move the resulting **myCobotWiiRemote-main** folder to the **CDPStudioWorkspace/systems** folder.

03 Download and build library

To deploy the project to the robot arm, you'll need a couple of libraries. If you don't already have the myCobotLib library from the previous tutorial, go to the GitHub repo at **magpi.cc/mycobotlib**, click the Code button and Download ZIP again. Extract it and then move the resulting **myCobotLib-main** folder to the **CDPStudioWorkspace/libraries** folder.

Open the myCobotLib.pro project file in CDP Studio, check ARM 64-bit is checked in the Deploy Configuration tab, then right-click its name in the left panel and select Build.

You'll also need the xwiiremotelib library at **magpi.cc/xwiimotelib** and the xwiimote



You'll Need

- Windows or Linux PC
- CDP Studio 4.12 **cdpstudio.com/getstarted**
- myCobot 280 Pi robot arm **magpi.cc/mycobot280**
- myCobot Adaptive Gripper **magpi.cc/mycobotgripper**
- Wii Remote and Nunchuk

submodule on which it's based at **magpi.cc/xwiimote**. You can either clone the library with the recursive option:

```
$ git clone --recursive https://github.com/
CDPTechnologies/xwiimotelib.git
```

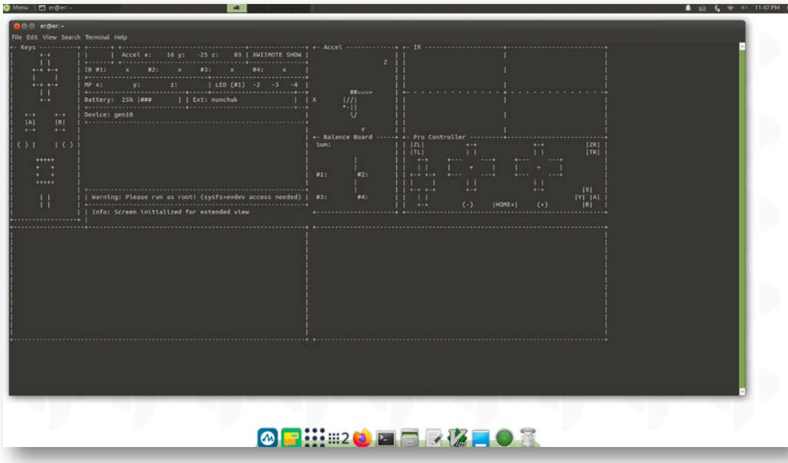
Or you can download and extract the ZIP file, then download and extract the xwiimote ZIP and place the folder's contents into the library's xwiimote subfolder.

Move the **xwiimotelib-main** folder to **CDPStudioWorkspace/libraries**, then open the xwiiremotelib.pro project file in CDP Studio. Before building the library, open the Deploy Configuration tab for the wiimoteIO component and check that the ARMv8 64-bit (Debian 11) toolkit is enabled. If you get errors when building it, make sure CDP Studio has been updated (see Step 1).

04 Open the project

Now open the main **myCobotWiiRemote.pro** project file in CDP Studio. In the left panel of the Configure window, you'll note that it comprises a myCobotWiiRemoteController application with various components. A key part is the Kinematics-based ArmDHModel, which features a DHChain Visualizer pane that can be used to view the arm positions on-screen in 3D. This can be used even if you don't have a real arm connected, so you can still run the project and see how your Wii Remote and Nunchuk actions affect its movements.

Pair and then connect the Wii Remote controller with the arm using the Bluetooth Manager in Ubuntu



▲ You can test the Wii Remote with the 'xwiishow 1' command in a terminal in the arm's Ubuntu OS

05 Prepare myCobot

If you've already set this up in the first tutorial, you can skip the first part of this step. The myCobot arm's Ubuntu OS has a non-standard version of the OpenSSH server. So you'll need to make a small change to a config file so CDP Studio can communicate with it over the network. SSH into the myCobot with the username 'er' at its IP address; the default password is Elephant. Then enter:

```
$ sudo nano /etc/ssh/sshd_config
```

Locate the line that sets the PubkeyAuthentication parameter and set it to yes (and make sure the line is not commented out). Press **CTRL+X**, then **Y** to exit and save.

Restart the OpenSSH server with:

```
$ sudo systemctl restart sshd
```

06 Pair the arm with CDP

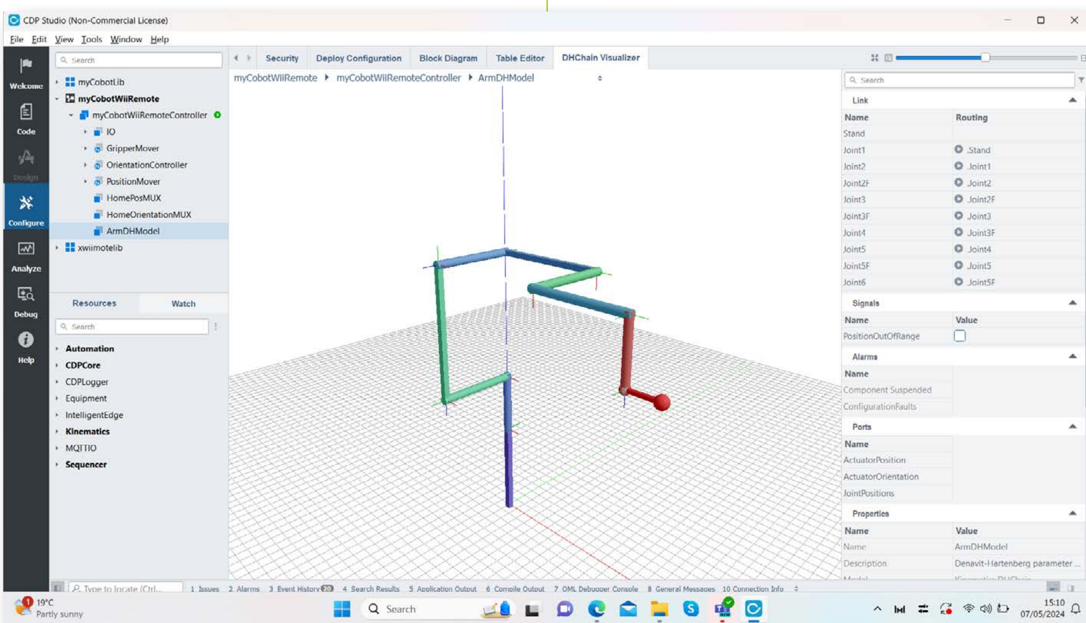
Open the Deploy Configuration tab for myCobotWiiRemoteController. Under Networks, press the Select button for 'WiFi'. The 'Devices – WiFi' table below should start showing any devices available to pair with CDP Studio. Click the Username field for your myCobot (based on its IP address) and enter 'er', then click the Pair button next to it. You will be prompted to enter the password – the default is Elephant.

Under Applications, for Device select your myCobot IP address or name, then change the Toolkit to ARMv8 64-bit (Debian 11). When you run the myCobotWiiRemote project, it will then be deployed over the wireless network to the robot arm.

07 Pair the Wii controllers

You'll need to pair the Wii Remote and Nunchuk controllers via Bluetooth with the robot arm's Raspberry Pi. First, open the battery compartment of the Wii Remote and press the small red Sync button to start pairing; the Remote's blue player LED should start blinking.

Now, from the robot arm's Ubuntu MATE desktop (viewed on a monitor or remotely via



▲ You can view the arm's movements on-screen in the ArmDHModel DHChain Visualizer

Top Tip

Another arm

While this project is designed for the myCobot 280 Pi, you could use a different robot arm – you'd just need to create a new IO library to communicate with it.

VNC), open the Menu (top left) then search for and open Bluetooth Manager. Click Search and you should see the Wii Remote, possibly as ‘Nintendo RVL-CNT-01’; select it and choose Pair. The Remote’s LED should stop blinking.

08 Run the project

Right-click myCobotWiiRemote in the left panel of CDP Studio and select Run & Connect. If you have a myCobot arm connected, it should follow the movements you make with the Wii controllers; if not, select ArmDHModel in the project’s left panel to view a 3D representation of the arm with its six joints. The gripper status is indicated by a green (closed) or grey (open) dot.

By default, the arm’s servos are released. Press the Remote’s 2 button to engage them. Now hold the A button and tilt the Remote to tilt the arm’s endpoint accordingly. Note that if you move outside the arm’s range, the Remote will rumble. Pressing the Home button returns the arm to a preset home position.

The Nunchuk’s joystick can be used to move the arm’s endpoint forward, back, left, and right. When holding the Z button, you can also tilt the Nunchuk to move the endpoint up and down. Pressing the C button toggles the gripper status between open and closed.

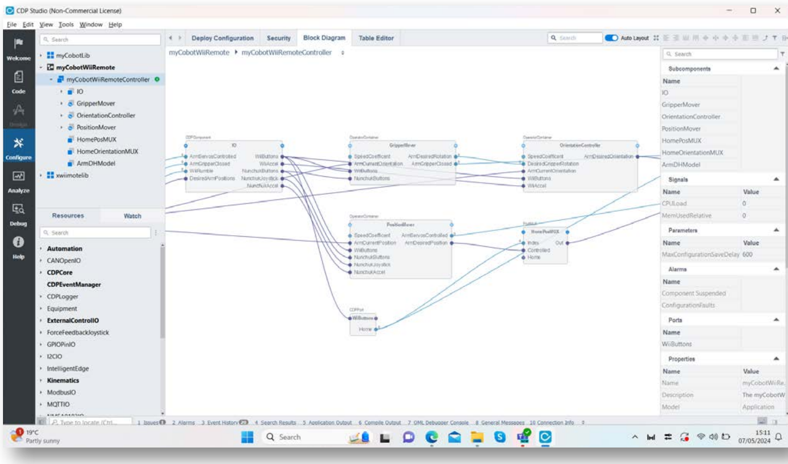
To disengage the servos again, press the Remote’s 1 button, but be ready to catch the limp arm as it falls!

09 Kinematics

This project makes use of CDP Studio’s Kinematics framework, in the form of the DHChain component. The basic concept of kinematics is that if you input joint angles for a robot arm, or chain of links, the framework can calculate the end position in 3D space. This is used to control the arm’s joint movements to reach a certain x/y/z position, such as for the home position and those reached via the Wii and Nunchuk movements.

Kinematics has many uses in the field of engineering, helping to calculate positions and velocities of moving parts such as those in an industrial robotic arm, or a bionic limb or exoskeleton. An example real-world case is the use of CDP Studio and kinematics for controlling deck cranes on ships.

You can see how the project’s components connect to each other in the Block Diagram view



10 Exploring the project

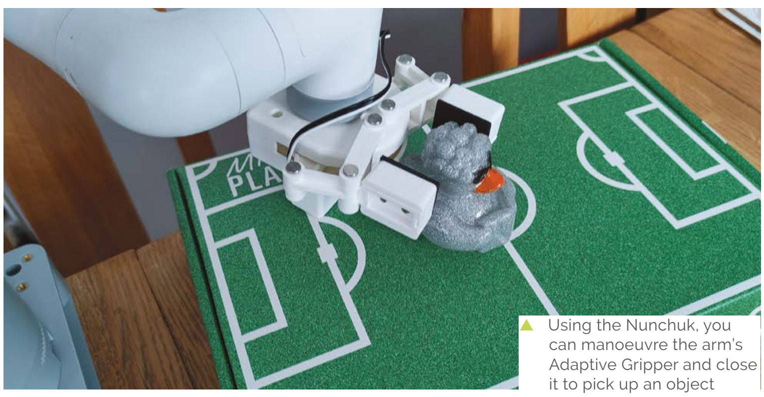
You can click the Block Diagram tab to see how the project’s block-based components have been put together. These include an I/O block to interpret the controller actions, along with blocks for the desired arm position, gripper orientation, and gripper open/closed status. A couple of mux blocks enable the arm’s home position and orientation to be triggered. The ArmDHModel block calculates the arm joint angles required for a required position, and also triggers the Wii Remote rumble if a position is out of range.

To take the project even further, you could add some extra actions for the unused controller buttons – by opening the **xwiimoteIO.cpp** code file and adding events and return codes for them there, then creating actions for the latter in the main application.

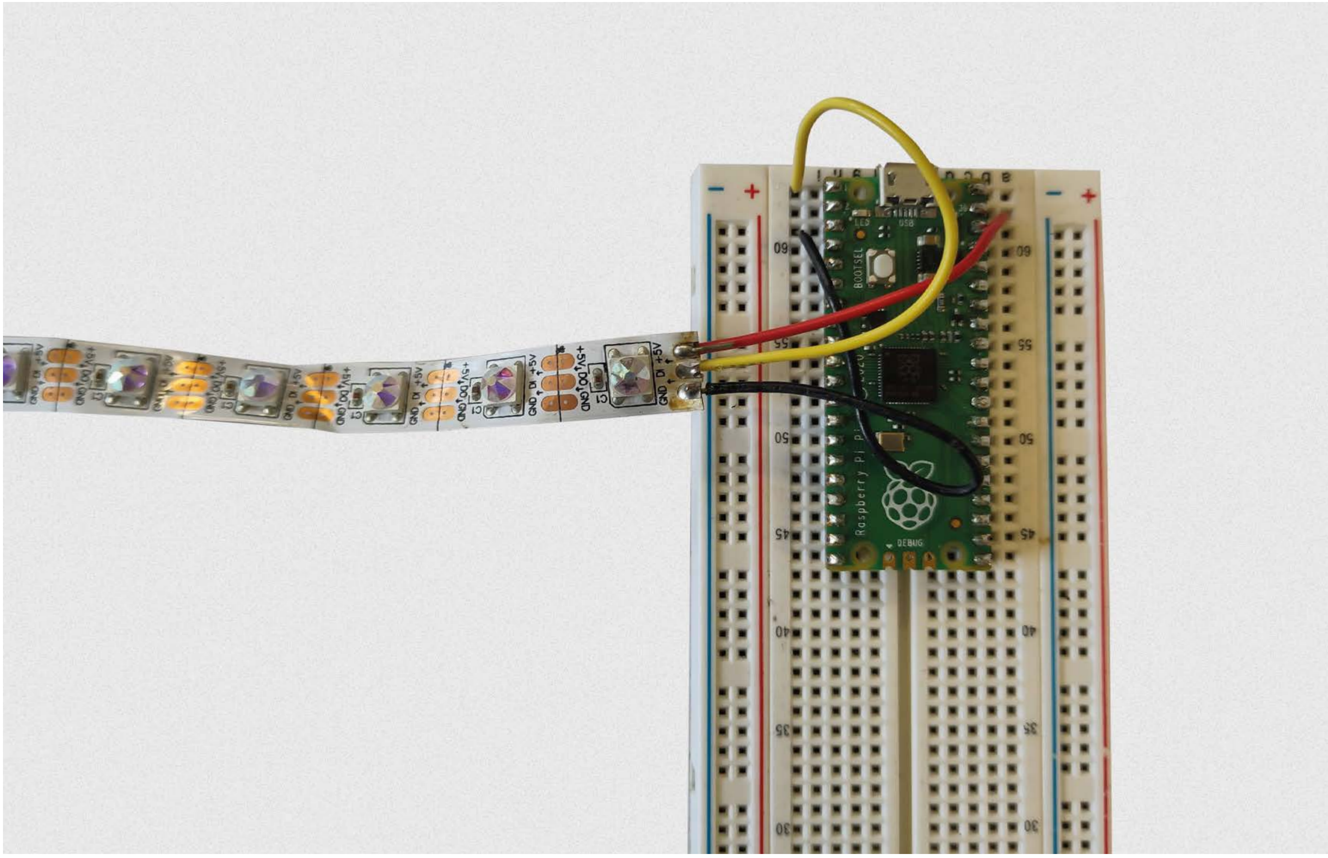
Top Tip

No arm?

You can still run the project without a robot arm, by deploying it to a Raspberry Pi (or other Linux PC). Just make sure the ARM toolkit used matches the 32-bit or 64-bit architecture of its OS.



Using the Nunchuk, you can manoeuvre the arm’s Adaptive Gripper and close it to pick up an object



Zero-code LED animations with Pico

Add a little sparkle to your life

Ben Everard

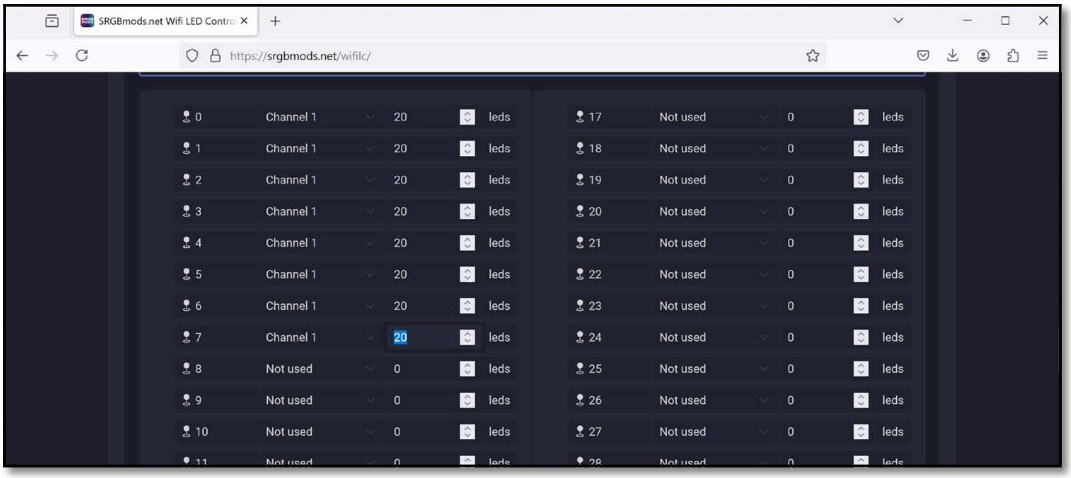
Ben's house is slowly being taken over by 3D printers. He plans to solve this by printing an extension, once he gets enough printers.

LED effects are a great way to light up any occasion. Here in the UK, Christmas is the most famous holiday for decorating rooms with lights, but many other cultures have other events that include unnecessarily elaborate lighting displays. Besides, there's no need to limit yourself to traditional holidays – you're an independent person who can light up the night whenever you feel like it. In this article, we're going to look at one way of getting started with LED effects quickly and cheaply that you can use for any occasion.

OK, we'll own up right at the start. We said zero code in the title – and that is true; you don't have to write a single line of code – but you do have to compile the automatically generated code yourself. Let's take a look at what this means.

You can use a Raspberry Pi Pico, Pico W, Adafruit Feather RP2040 SCORPIO, or an Arduino Nano RP2040. Other RP2040 boards may work, but they're not officially supported, so it's possible you'll run into problems.

There are two flavours of the firmware: the USB version (**srgbmods.net/lcv1**), and the wireless version (**srgbmods.net/wifilc**).

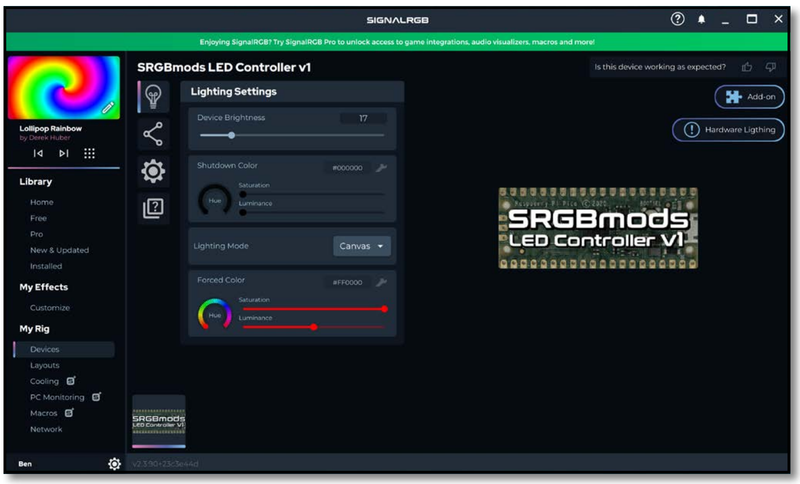


Left ◆
There are just three connections to control your LEDs

Above ◆
You need to define your setup before you download the firmware

Right ◆
In SignalRGB, you can partition your LEDs however you want

> **While there isn't specific support for LED matrices,** in most cases, you should be able to get them to work



On this page, you can select which GPIO pins are used for outputs and how many LEDs are on each pin. The GPIO pins have to be sequential. We went for GPIOs 0–7. There's not a fixed limit on the number of LEDs on each pin, though you will run out of RAM at some point. The more LEDs, the slower the updates are, so we'd recommend limiting it to about 100 or so per pin.

While there isn't specific support for LED matrices, in most cases, you should be able to get them to work – see the box overleaf for details.

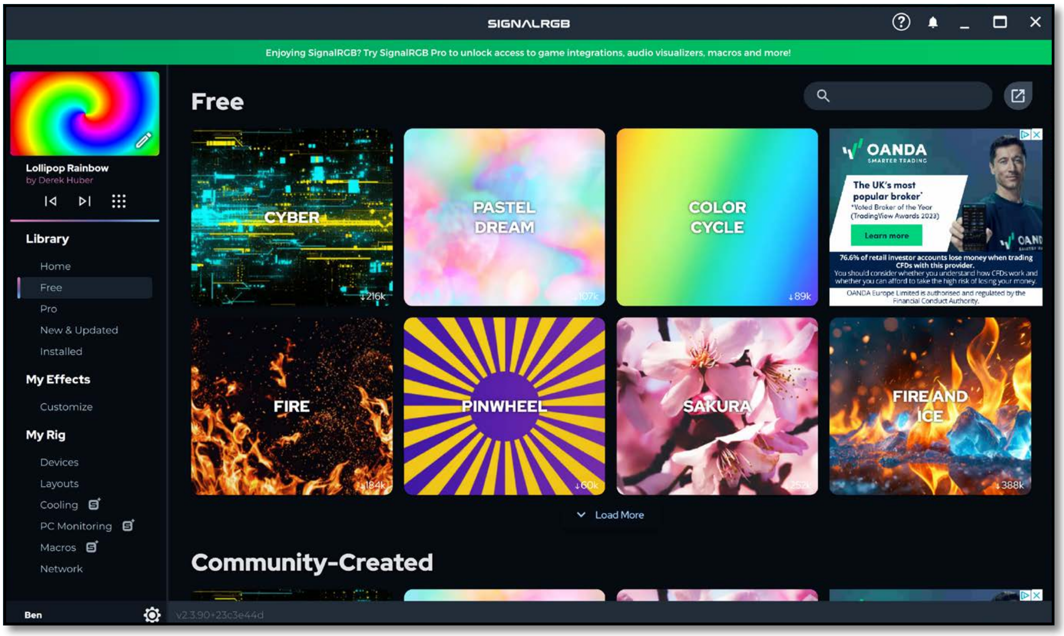
Once you've selected your configuration, click download and you'll get a zip file that bundles the code together. →

CREATING YOUR OWN

Using other people's animations is a great way of getting a good-looking setup quickly, but sometimes you want a personal touch.

Lighting effects are known as Lightscripts, and they are essentially web pages powered by JavaScript. There's full documentation on creating your own at: **hsmag.cc/LightScripts**.

SignalRGB is designed to work with games, and there's a full API to send events to the running effect that lets you change it. Using this, you could take input from sensors and have it change the way a particular effect is displayed.



Right There are loads of pre-made animations you can use

POWER PROBLEMS

For short runs of LEDs, you can just connect them directly to the power supply on your microcontroller. However, as you connect more and more LEDs, they might start to draw more power than your microcontroller can supply.

This can become a complex problem. The Adafruit NeoPixel Überguide has excellent information on this: **hsmag.cc/PowerNeoPixels**.

COMPILING CODE

The code is for the Arduino IDE, so you'll need to download this from **arduino.cc/en/software**.

There are a few bits you need to configure in this – take a look at the red box on the firmware page (where you just set your configuration). It's a bit different between the two versions of the firmware, but make sure you follow them, otherwise you'll have problems. Once all this is done, plug your microcontroller into your computer via USB and click the arrow button to compile and upload.

The SRGBmods firmware works with WS2812B LEDs (aka NeoPixels). These typically come in strips, but you can get them in different form factors. Your LEDs should have three connections – one for power, one for ground, and one for data. The simplest possible configuration is to connect ground to ground on the microcontroller, power to VBUS, and signal to the appropriate GPIO pin.

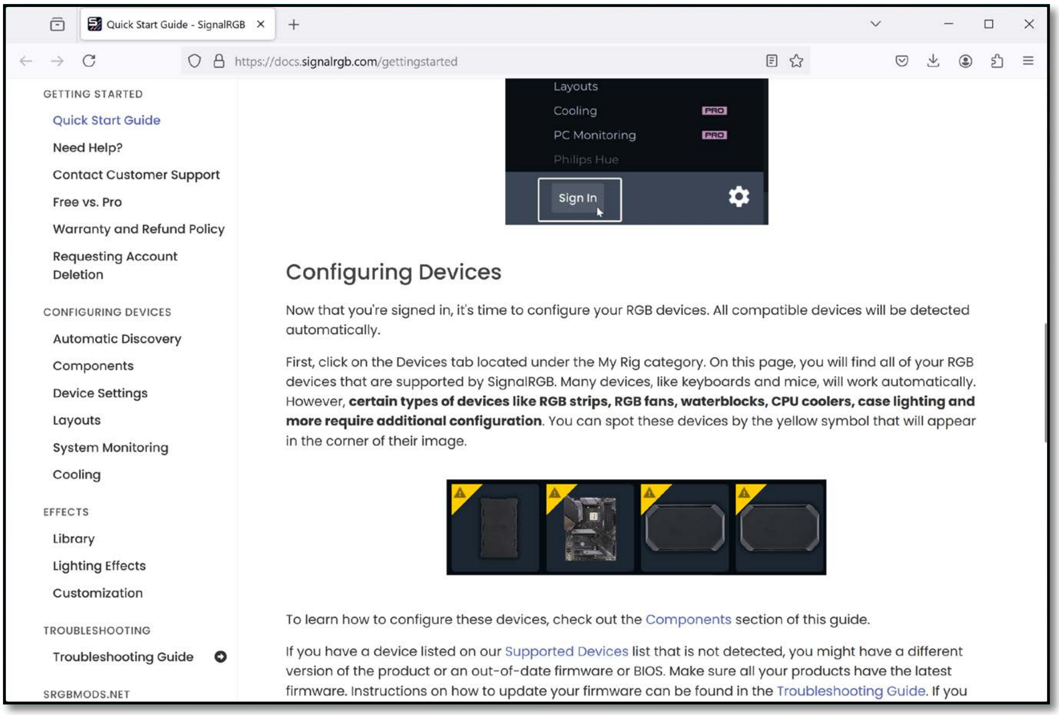
Now it's time to set up the software on the PC side. You'll need the SignalRGB software, which you can install from **signalrgb.com**. This is primarily designed for controlling the LEDs in fancy computer peripherals – the sort of setup where you have the keyboard backlights moving in time with the lights on the CPU cooler. We're not going to do any of that, but we can use the same system to control our LEDs.

Once you've downloaded and installed it, you should be able to run it like any other application.

The next bit depends slightly on whether you've used the USB firmware or the Wi-Fi firmware. If you've used the USB firmware, then go to the devices option in the menu, and you should see an entry for SRGBmods LED Controller v1 (as well as possibly any other RGB hardware you have on your machine). If you don't, you might find that you need to set it to run the software as administrator (follow the guide here: **hsmag.cc/AdminSignalRGB**).

If you used the Wi-Fi firmware, then go into the Network menu, select SRGBmods from the list and follow the wizard to attach the device. You will need to know the IP address of the device – you should be able to find that out via your router's admin interface.

The primary unit of SRGB isn't devices, but strips. As far as SRGB is concerned, strips aren't physical strips of LEDs joined together, but logical strips that you create in the application.



Left There's good documentation for using SignalRGB at signalrgb.developerhub.io

In the device section, go to the component config tab (which confusingly has an icon of connected circles usually used for social sharing). Here, you can click the '+' to add a new strip. Change the LED count to whatever you want, then press Create to create the strip. This will use the first chunk of LEDs connected to your Pico, starting with the physical strip connected to the first GPIO and then overflowing, if necessary, onto the next physical strip. This isn't based on the number of LEDs you have actually connected, but the number that you entered into the config box when you created the firmware. If you want, you can then create additional strips until all the LEDs are accounted for.

SRGB animations are two-dimensional, and you can place your various strips within this 2D space. This means that if you have multiple strips, you can place them so that they display suitable parts of this 2D pattern. This is all set up in the Layout section.

Here, you should see an entry for the device, which can drop down to show the various strips it contains. Click on these to add them to the layout, and you can move them around to capture the bits you want. In the bottom right, there's a pane where you can control the position, scale, and rotation precisely, which is useful if you want to position multiple strips relative to each other.

ANIMATION

We've now done all the setup work, but we haven't yet got an animation. There are 'pro' and 'free' animations. We've been playing with the free options, but no-doubt there are some interesting choices available in the paid-for tier as well.

Go to Library > Free in the left-hand side, and you should see the options. Click on an option to download it and you should then see it playing at the top of the left-hand pane. It should also start displaying on the LEDs at this point.

Any that you've downloaded also appear in the Installed section.

You should now have your LEDs flashing away according to the pattern you've picked. Have a hunt around the different options to find a setup you enjoy. You get the best effect when you use multiple strips to build up part of the 2D pattern. Remember the golden rule: if in doubt, add more LEDs.

MATRICES

While LED matrices aren't explicitly supported by SignalRGB, you can use them. Typical LED matrices are wired in rows, so all you need to do is create strips for each row and place them appropriately on the layout. If your matrix has a zigzag layout, then you can just rotate every other row by 180 degrees.

HackSpace
TECHNOLOGY IN YOUR HANDS

FIELD TEST

HACK | MAKE | BUILD | CREATE

Hacker gear poked, prodded, taken apart, and investigated

PG 92

PRUSA MMU3

Turn plastic noodles into multicoloured gizmos

PG 96

CROWDFUNDING

Manage your stack of rechargeable AA batteries ... if you still have them

PG 86

BEST OF BREED

DIY remote controls

ONLY THE BEST

Remote control

Kits and accessories that allow you to control your world

By **Marc de Vinck**

I've always loved radio-controlled planes, cars, and boats. I've had so many different types of RC toys as a kid, including my earliest memory of an R2-D2. It was so much fun to tank-steer it around and make its head spin while my dog barked frantically at it. I think it was that toy that eventually led to me building my own radio-controlled planes, and even large-scale helicopters once I was a bit older and had the skills and willpower to tame those early non-gyros-enabled 'copters. You name it and I probably built it, and crashed it, at some point.

And, as advanced as hobby remote controls have become over the years, including the ability to do extensive customisation and programming, they aren't always the perfect solution for your DIY build. A custom-built controller can be very inexpensive and customisable to your specific needs without all the extras. Sometimes you just need a wireless button, or a system that works with a specific radio frequency, or not a radio at all and simply works via IR light. And that's where this Best of Breed comes into play. I'll be looking at a few DIY remote control solutions for your next build.

SparkFun Wireless Joystick Kit vs RPi-Spark pHAT for Raspberry Pi

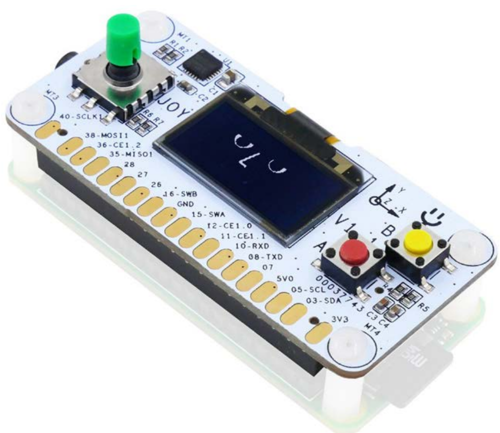
SPARKFUN $43.95 | sparkfun.com

TINDIE $24.95 | tindie.com

The SparkFun Wireless Joystick Kit makes adding reliable and robust remote control to your project easy. What makes it so robust? Well, it's built to be used in conjunction with an XBee radio. And anyone who's been doing electronics long enough knows how reliable the XB radios are when building remote control systems. You'll have to solder this kit together, but once done and you add your XBee module, you'll have precision dual joystick control with the circuitry for a light PO battery and charger. SparkFun has a comprehensive set of assembly instructions and example projects on its website, along with different XBee modules and accessories.

I like the RPi-Spark pHAT for Raspberry Pi designed by MobiNRG. Why? Because it encompasses most of the basic components that I find myself needing so often when programming any single-board computer or microcontroller. You get a joystick, two buttons, and a beautiful 128 × 64 OLED screen.

And if that wasn't enough, you also get an accelerometer, gyroscope, thermometer, and a 3.5 mm stereo headphone jack. You won't need all of that for every project, but quite often you need most of it, so it looks like a very useful add-on to your Raspberry Pi. Head on over to the website to learn more about this product.



VERDICT

SparkFun Wireless Joystick Kit

If you use XBees, this is a good choice.

8/10

VERDICT

RPi-Spark pHAT for Raspberry Pi

A perfect companion.

10/10

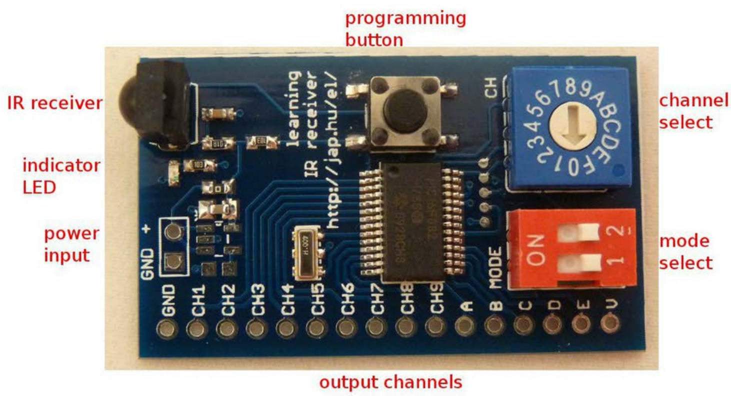
BEST OF BREED

Learning infrared remote-control receiver

TINDIE $20 | tindie.com

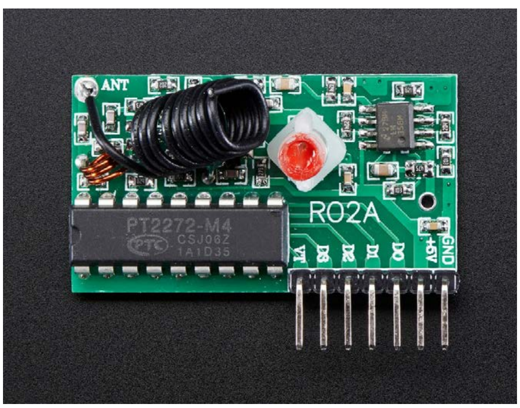
The Learning infrared remote-control receiver, designed by Peter Jakab in the United Kingdom, can be used to control basically anything. The receiver can decipher either RC-5 or NEC format remote control signals. This allows you to learn the signals of most of your off-the-shelf remote controls, like your TV, and integrate them with your electronics.

The receiver has 14 output channels, and each channel can have up to four button actions: on, off, toggle, and momentary-on. Head on over to the website to learn more about how the board is programmed, and all the different functions it is capable of outputting.



Simple RF M4 Receiver

ADAFRUIT $4.95 | adafruit.com



Simple RF M4 Receiver available from Adafruit is a classic RF receiver that works on the same frequency as many equally as inexpensive remote controls. There is no programming, no configuring, or addressing of any kind. All you have to do is provide the board with 5V DC and press the matching button on the key fob remote. Press A on the remote and pin 1 goes high, press B and pin 2 goes high, etc., etc. This is a really easy way to make a remote-controlled switch integrated into your project when you don't have line of sight. Just keep in mind when you pick up this board, you also need to pick up a matching key fob remote.

VERDICT

Learning infrared remote-control receiver

Convert your remote quickly.

8 /10

VERDICT

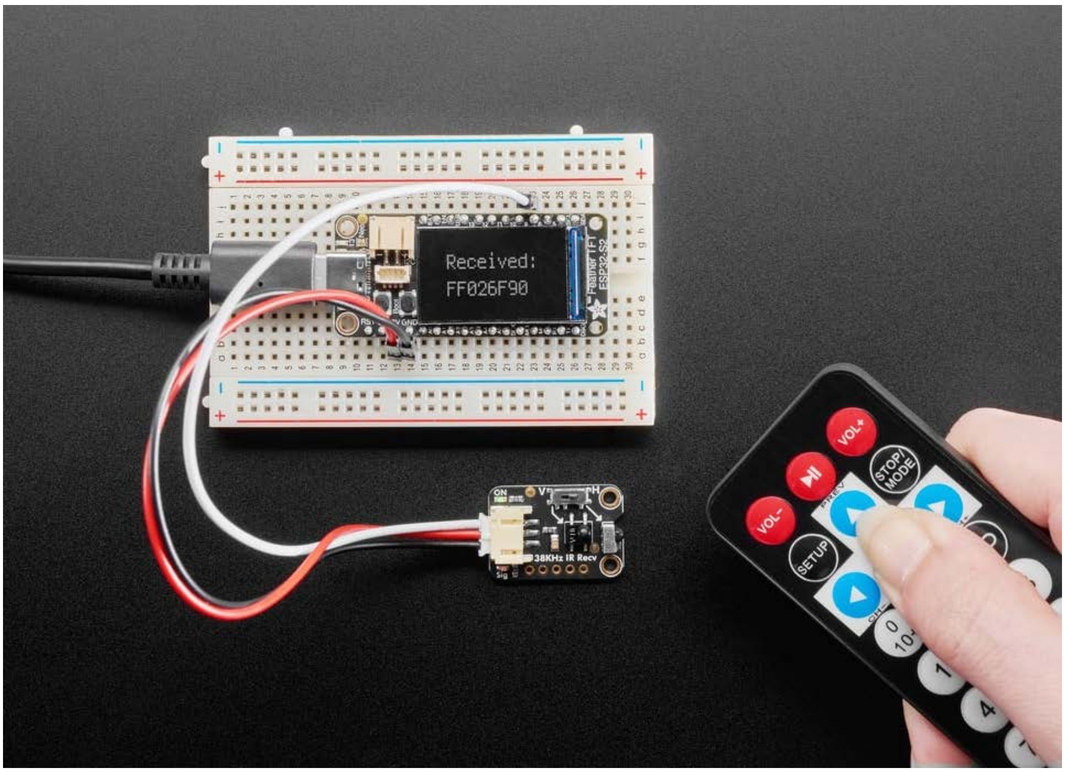
Simple RF M4 Receiver

Simple and affordable remote control.

9 /10

Adafruit Infrared IR Remote Receiver

ADAFRUIT $4.95 | adafruit.com



The Adafruit Infrared IR Remote Receiver has to be one of my favourite products in this roundup. Why? Simply because I have played around with IR receivers before, and they can be finicky. This breakout board, featuring Adafruit's STEMMA connector, can quickly and easily add an infrared receiver to your project.

One interesting feature of this product is the fact that it includes two IR receivers – one vertical and one horizontal. This makes receiving signals very reliable. The board was designed to work with 38kHz signals, which are very common in inexpensive remote controls. And, if you don't have a remote control, you can pick one up from Adafruit too!

VERDICT

Adafruit Infrared IR Remote Receiver

This should be a go-to board if you need IR remote control.

10 /10

BEST OF BREED

micro:GamePad – GamePad for micro:bit

DFROBOT ◈ $19.90 | dfrobot.com

The GamePad for micro:bit (V4.0) is like it sounds: a well-designed micro:bit-based gamepad with a joystick and buttons. The controller features an analogue two-axis joystick, seven programmable keys, a vibrating motor, and LED. All this is mounted on a nice-looking black PCB with an acrylic faceplate. All you need to do is pop in a couple of batteries and a micro:bit and you have quick access to precision controls and buttons for your project. If you were thinking of building a robot with your micro:bit, this is a must-have accessory.

3DRacers – 3D Printed RC Car Kit – BLE + Arduino

TINDIE ◈ $59 | tindie.com

I may have left this kit as the last one to review in this Best of Breed, but the truth is, it's what inspired the remote control theme. Designed by Marco D'Alia of 3DRacers in Italy, the kit features a Bluetooth Low Energy (BLE) radio and an ATmega32U4 microcontroller. But what makes this kit interesting is you have to 3D-print your own car body. The designer has ten different car bodies available, and 100 different accessories that you can download from the online forum.

Once you print and assemble the chassis, you can program it just like a standard Arduino. The board does come preprogrammed, but I'm sure most people will want to start modifying their microcontroller after a little bit of testing.

And if you're wondering how you control it, wonder no more! The creator also has a free smartphone app that you can download. Head on over to the website to check out more about this fun and open-source project.

VERDICT

micro:GamePad – GamePad for micro:bit

A great controller for your micro:bit.

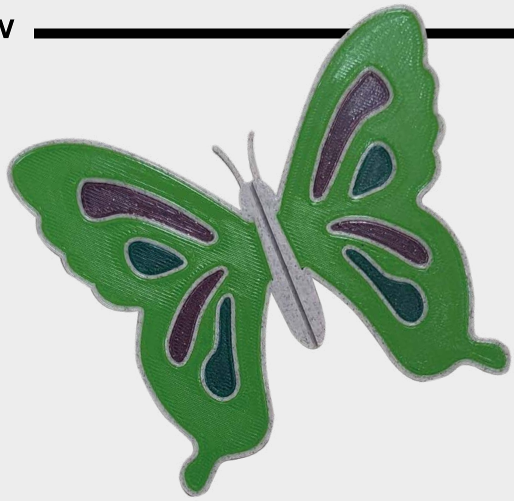
9 /10

VERDICT

3DRacers – 3D Printed RC Car Kit – BLE and Arduino

So much fun!

10 /10



Prusa MMU3

Add five colours to your printer

PRUSA RESEARCH ◆ **£292.80** | **hsmag.cc/mmu3**

By **Ben Everard**

Above ◆ A few of our test prints – we're particularly fond of the purple galaxy sloth (design by Real 3D Prints)

The Multi Material Unit 3 adds the ability to change between five different filaments to Prusa MK3S+, MK3.5, MK3.9, and MK4 printers. You can also get the upgrade parts to turn an MMU2 into an MMU3.

The MMU3 sits between a bank of five filaments and the extruder of the printer. Each time the printer needs to change colour, the filament is automatically unloaded from the printer and the next filament is loaded.

We got the kit with 3D-printed parts included. This makes things a bit easier, as everything comes in helpfully labelled bags and you can get started straight away. However, it's £32 cheaper to print them yourself, and Prusa includes the filament to do this. You can also get the tools needed to build it for an additional £16, but most makers will already have them, as there's nothing particularly unusual required.

Prusa printers have a reputation for being big builds, and this is no exception. Expect it to take about a day to fully assemble and get working. It's a surprisingly complicated bit of kit but, thankfully, the guide is excellent and we didn't encounter any problems with the build.

Throughout our testing, only one thing has caused us problems – too much resistance in the filament path. If this happens, the feed motor on the MMU can't pull the filament through into the printer. The resistance came from a couple of sources – using a cardboard spool, and trying to cram everything onto too small a table. The cardboard spool didn't get on particularly well with the roller-style filament holder (the supplied one has plastic wheels rather than bearings, so doesn't run as freely as some designs that we've used). The too-small table caused the PTFE tubes to have too many bends.

You don't have to use the supplied filament holders – all they do is hold the spools and feed the filament into PTFE tubes. If you want to use the MMU3 in a small space or with cardboard spools, it would be pretty straightforward to create a setup that would work.

Once we got the friction out of the system, the only failed prints we've had in our testing were caused by user error (we sliced them for the MMU2 rather than the MMU3).

Multi-material printing is slower and uses more filament than single-colour printing (this is true of all 3D printers, except possibly the Prusa XL). The MMU is the fastest filament changer we've tested, but it's hard to give an idea of how much slower it is than single-colour, because it depends so much on the model.

CHOOSING WHAT TO PRINT

As with all 3D printing, the easiest thing to do is download pre-created models and print these, rather than doing the dirty work of printing your own. This is perfectly possible with multicolour prints as it is with single-colour prints. A quick scan of Printables with the MMU keyword brings up plenty of things to print. However, very quickly, you'll realise a problem – most models need a very specific set of colours to work, and unless you want to create a library of filament, you're probably going to be quite limited with what models you can download and print. This might become less of an issue as more and more people use multicolour 3D printers, and the bank of available models increases. We'd love to see some ability to search the available models by filament colour, to help you find things you can print with the filament you have.

There are a couple of ways of colouring your own models. Firstly, you can export your model from whatever CAD software it's designed in as multiple different parts, and assign each part a different colour. Alternatively, you can use PrusaSlicer to paint your model with the colours you want. The former requires you to be familiar with CAD. The latter works reasonably well (and certainly as well as any other 3D printer slicer we've used). There is also a sort of hybrid approach where you add parts to a model in PrusaSlicer. Using this, you can add text or graphics (in SVG format) to an existing model.

It does feel like the software is the weakest part of multicolour 3D printing at the moment. We'd love to see some more innovation in this area.

Whichever way you get your models, 3D printing in colour is more work than printing single-colour, but you do get fantastic-looking parts as a reward.

Another use for the MMU3 is 'joining' spools of filament. This means that you can print from one spool until it runs out, then it will automatically keep printing with the next spool, and so on. This is particularly handy if you print large models and get left with small amounts of filament on the spool that aren't big enough for a print by themselves.

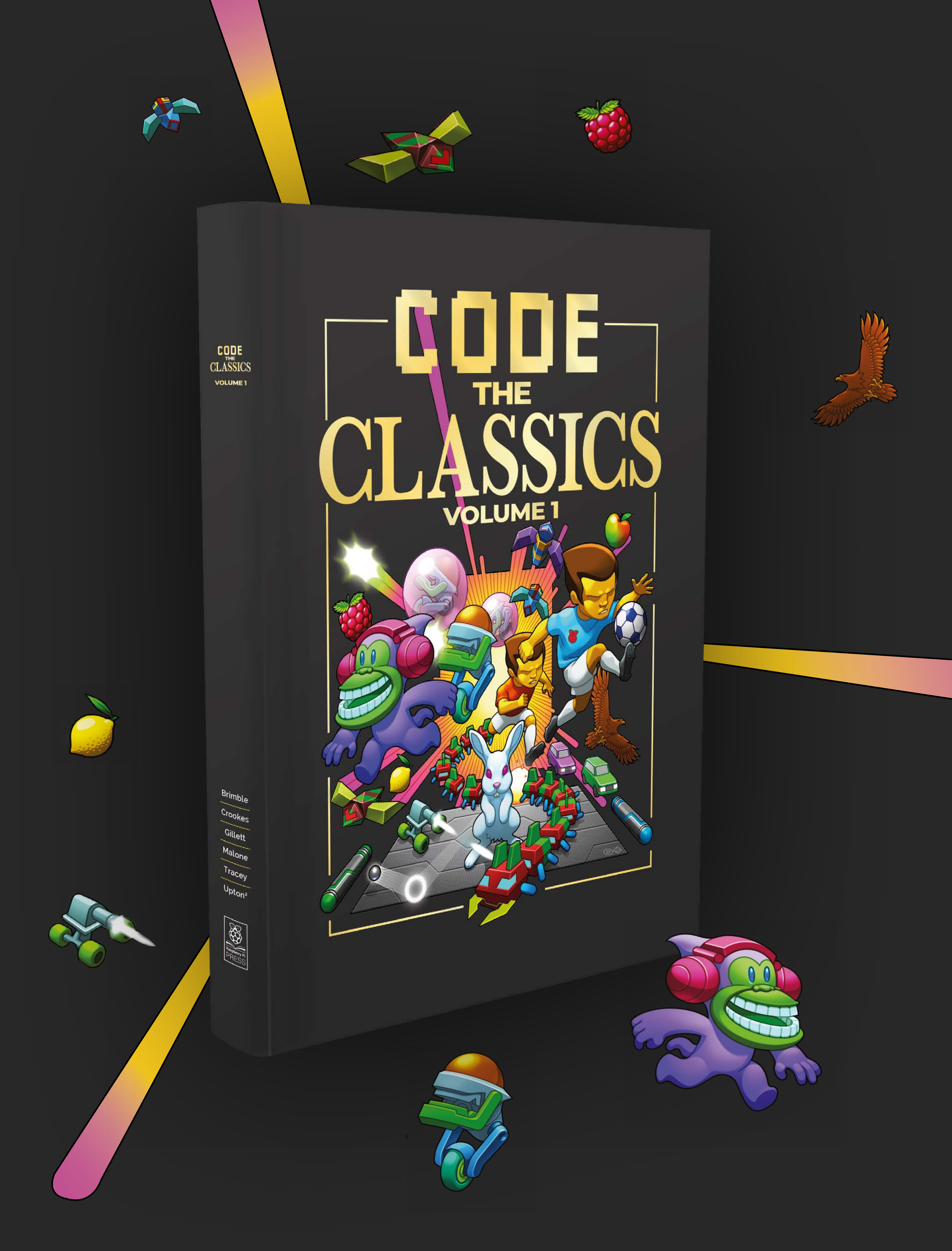
After quite a long and involved build process, we found the MMU3 to be easy to work with and reliable. If you take the time to design your parts for the filament you have, you can create some excellent-looking parts. □

Above The main unit clips on top of the printer and feeds filament into the extruder

VERDICT

An easy-to-use and reliable way of creating colourful prints.

9 /10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CROWDFUNDING NOW

Olight Ostation X

Always have a battery ready

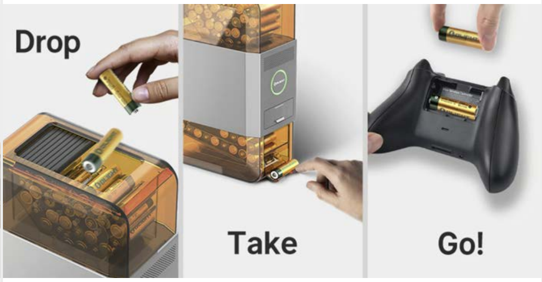
From £79 | **hsmag.cc/olight** | **Delivery:** Nov 2024

According to the campaign, you just plop your batteries in the top, and the Ostation X sorts them, charges them if necessary (detecting the polarity and chemistry before it does so), and – once fully charged – presents them ready to be used.

Sometime around 1999, AA batteries were a major consideration for this reviewer. His Walkman (he never got a portable CD player) chewed through them, as did his family's digital camera (this was an unusual item in the 1990s). Bike lights and torches chewed through them, (while LEDs had only just been invented, and hadn't yet made it as far as his house in rural Worcestershire). Back then, an automatic AA battery sorter and charger would have been amazing – probably one of his most treasured possessions.

Alas, time has moved on. A huge number of the things that we once powered with AA batteries are now not devices at all, but apps on a lithium-powered phone. AA-powered devices are a rarity.

However, it's unfair to judge a product by one person's use case. If you have to juggle little batteries in and out of chargers to make sure that you always have power, then this might just be the thing you need. □



Below This looks like an solution to a problem we don't have

Flovv and Flovv-e

Desktop injection moulding – sort of

From £512 | hsmag.cc/flovv | **Delivery:** Nov 2024

There's a long history of manufacturers trying to jam other machines into 3D printers. We've seen 3D printers that convert into laser cutters, and 3D printers that convert into CNC machines, but this is a new one on us – a 3D printer that converts into an injection moulding machine.

Before you rack your brains trying to figure out how it works, we'll spoil the surprise that is well hidden in the Kickstarter page – it's not an injection moulding machine. At least, not in the sense you're probably expecting. It's basically a resin pump that automatically mixes two-part resins. There's then a hose that lets you deposit this premixed resin into your 3D-printed mould. This is known as Reaction Injection Moulding (RIM), and is an entirely different process to the sort of injection moulding that uses hot plastic.

The combined printer and resin pump comes in at about £2133, which seems a lot for an unproven 3D printer plus the ability to pour resin. It's possible that this is a big 3D printer – it certainly looks big – but the only information is the external dimensions which aren't really very helpful.

If you do a lot of casting, then the standalone resin unit (£512) might be useful. It might let you mix exactly the right amount of resin, make sure it's evenly mixed, and generally reduce the amount of complexity of dealing with toxic liquids. However, without testing it out, we can't say if it lives up to this promise.

Left Take the mess out of resin pouring

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.

WE HAVE IMPORTANT NEWS!

This will be the last issue of HackSpace as a standalone magazine. Starting next month, HackSpace will become part of The MagPi – the official Raspberry Pi magazine.

For the past six and a half years, we've poured our heart and soul into this great magazine. We've had a great time both building projects and seeing the amazing projects that you have built.

In some ways, this is a happy time. By bringing HackSpace into The MagPi, we're continuing to give space for makers in print media, and securing this space for the future. This space for makers works both ways – it means there's space for you to learn and see the great projects others are making, and it also means there's space for you to teach and show off the great projects you're making. HackSpace always was a place both by makers and for makers, and as part of The MagPi it will continue to be so.

I want to say a massive thank you to all the people who have made this possible: to all the contributors and interviewees, to all the people who make the projects and hardware we've featured, and to all the readers who are joining us on this journey.

Thank you for making the last 81 issues possible. We hope you'll join us and our friends from the official Raspberry Pi magazine as we take our next steps.

Best wishes,
Ben Everard and Lucy Hattersley

SUBSCRIBER?

Your subscription to HackSpace will be automatically transferred to The MagPi – the official Raspberry Pi magazine unless you already subscribe to that magazine in which case, you'll be automatically refunded.

You'll receive details shortly, but if you have any concerns, please reach out to customer service by email at hackspace@subscriptionhelpline.co.uk or by phone on +44 (0)1293 312193.

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