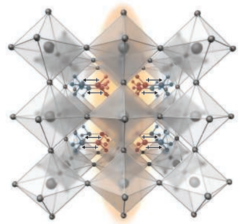
INSIGHTS

Fever control p. 1363

Explaining perovskite performance p. 1365 ▸



PERSPECTIVES

A remote tracking device can operate for longer periods of time if its system is designed to minimize power use.

PHOTO: DREW RUSH/NATIONAL GEOGRAPHIC CREATIVE

INSTRUMENTATION

Gathering lots of data on a small budget

Open-source hardware and software technology can redefine data collection

By **Aaron C. Greenville**[1,2] *and* **Nathan J. Emery**[3]

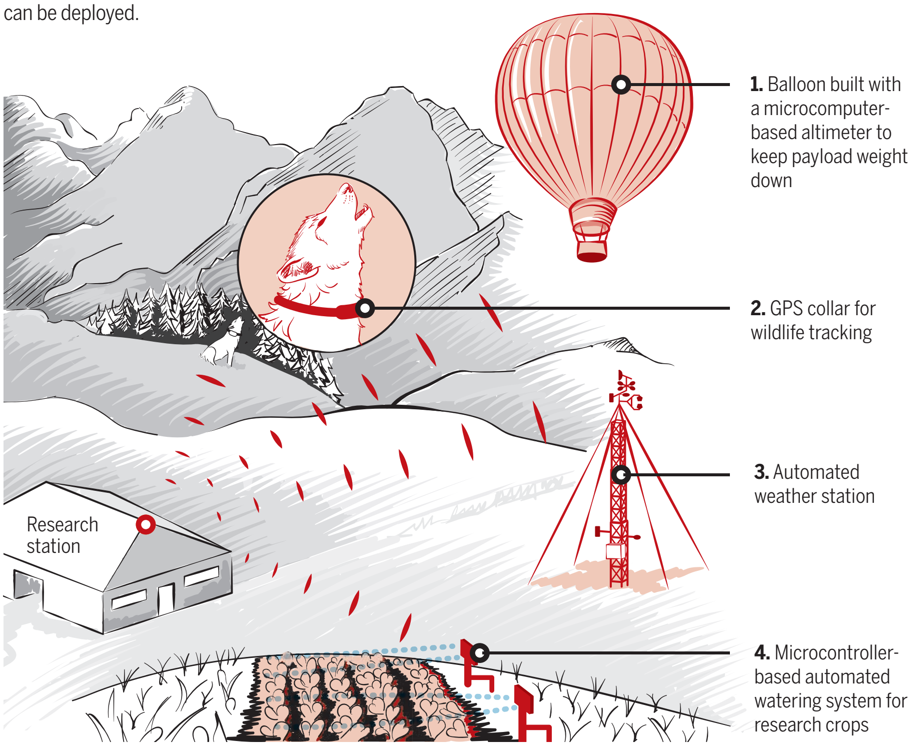
Many science research projects rely on specialized electronic devices and software to gather data that often come with a high price tag. Advances in open-source hardware and software are occurring at an astounding rate, but scientists are often slow to take advantage of these for purposes beyond their original scope. Here, we advocate that open-source technology can be easily applied in science research to collect large data sets, at the same time reducing costs and increasing the repeatability of experiments.

Open-source technology requires both computational resources and devices that can control and receive data from equipment. Two families of commercial products have spurred this development: Arduino microcontrollers and Raspberry Pi microcomputers.

The Arduino microcontroller electronics and software platform was introduced in 2005 and is now available from third-party manufacturers for as little as US$5. The Raspberry Pi, developed in 2012, is a credit card–sized microcomputer that includes important components for connectivity, such as an Ethernet port, and Wi-Fi and Bluetooth modules. It also enables multipurpose usage with USB ports, general purpose input/output (GPIO) pins, and operating system (OS) compatibility. Customizable storage with the micro-SD card slot allows users to run Linux, Windows 10 Internet of Things (IoT) Core, or Android OS, so it can serve as a central hub to interface with different devices and peripherals such as Arduinos, camera modules, and third-party wireless modules (*1*, *2*). The Arduino and Raspberry Pi platforms can be easily adopted by researchers who are familiar are frequently used for weather-monitoring stations [see, for example, (*4*)], but other applications include Global Positioning System (GPS) tracking (*5*), controlling wireless sensor networks (*6*), robotic pollination systems (*7*), soil-moisture probes and crop-water use (*6*), vision research (*8*), underwater imaging systems (*9*), and in quantitative polymerase chain reaction analyses (*10*). Similarly, the Raspberry Pi has been used for projects involving image capture and recognition (*1*), automated controllers for

Customizing environmental monitoring

The new open-source hardware environment can be used to build a range of cost-effective devices, as shown in an example of a multidisciplinary research station. A range of wirelessly connected sensors or remote data loggers can be deployed.



with the R software for statistical analysis and graphics, and Python software environments. Python code can be run on the Raspberry Pi, and the availability of prewritten software libraries (or code), like that for R, makes it easy to set up and run sensors and other components quickly.

The Arduino and Raspberry Pi can be used with open-source software for both field and laboratory-based research and can return cost savings up to a factor of 100 relative to commercial suppliers (*3*). Arduinos weather protection (*2*), and cardiac monitoring (*11*). Further uses for both devices could include laboratory and field automation (e.g., telescope dome opening and rotation, automatic feeding or watering systems, and photo-recognition controllers), a wide range of environmental sensors (e.g., gas, light, and cloud sensors), and spectroscopy. With the rise of the IoT environment, connecting and powering multiple devices are no longer limiting factors (*12*).

Several research groups have recently demonstrated the potential of the new open-source hardware environment, thereby illustrating the feasibility and practicality of developing custom devices. Fisher and Kebede (*13*) developed a microcontroller-based unit to monitor temperature and water status in cropped fields. The unit consisted of air, soil, and canopy temperature sensors and a soil moisture sensor, and required about 4 hours to build and test. Each unit was produced at a cost of US$84. Furthermore, all sensors were tested in controlled conditions before deployment in the field, and the accuracy of all sensors was within the manufacturer's specifications. Sreejith *et al.* (*14*) designed and built a microcomputer-based altimeter for high-altitude, lightweight balloon flights in astronomy. Using a Raspberry Pi equipped with an accelerometer, a magnetometer, and a gyroscope, the researchers could keep the total weight under a critical 6 kg. The cost savings of their custom altimeter were estimated to be 5 to 10 times that of commercially available products.

By combining open-source hardware and software, researchers can increase the repeatability and reproducibility of their studies. Researchers can share and publish the exact component list and wiring instructions to make their hardware, along with the code to run the device. Open-source device code can be published and made citable (*15*). The openness of these platforms allows researchers to harness global electronics design knowledge and increase multidisciplinary collaborations. The potential to roll out inexpensive data collection devices across global research networks provides an exciting opportunity to test ideas and explore general patterns across many scientific disciplines. The greatest strength of open-source technology is that any modifications to designs or codes are freely shared, which helps boost accessibility of the technology and repeatability of results. ■

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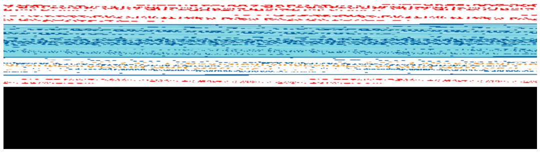

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Editor's Summary