I'm Dr Richard Bowman, a physicist creating cheap, high-quality open-source scientific and medical devices. We're testing 3D printed microscopes to diagnose malaria and monitor water quality in Tanzania, AMA.

Richard$_Bowman^1 and r/ScienceAMAs^1$

[1]Affiliation not available

April 17, 2023

Abstract

Hi reddit, I'm a physicist at the University of Bath, UK, working on microscopy and automated instrumentation. I'm very interested in using and developing open source hardware for scientific applications – particularly microscopes. Two projects I'm working on at the moment are developing high-precision positioning mechanisms that can be 3D printed, and creating automated microscopes for analysing blood smears to diagnose malaria. The project teams include scientists and engineers from the Universities of Bath and Cambridge, and Ifakara Health Institute and STICLab in Tanzania. All the hardware we've developed so far on these projects is open-source, available on GitHub, for example: https://github.com/rwb27/openflexure_microscope/ I hope that, by sharing our designs, we can enable small maker spaces and engineers like STICLab (https://www.sticlab.co.tz/) to produce, and indeed customise, sophisticated products with less reliance on expensive imported goods. It also makes it much easier for people to get involved with the research project, by hacking, tweaking, or replicating our hardware for their own use. Science relies on experiments being repeatable, but often University labs are full of black boxes (metaphorically – they're usually beige) which are expensive, hard to customise, and sealed up so you can't see how they work. Even worse, this proprietary hardware often won't talk to open software, making it difficult to integrate into complicated, automated experiments. There's a growing movement of people trying to open up scientific hardware – because this is good for science, even without the cost savings that can come from 3D printing many components in your lab. This is all explained much more eloquently in the GOSH manifesto and roadmap: http://openhardware.science/gosh-manifesto/ http://openhardware.science/global-open-science-hardware-roadmap/ I'm quite new to reddit, but I guess this is the part where I stop and let you take over – I'll be back at 10 am ET to answer your questions, ask me anything! Thanks everyone for the questions - it's been fun! I'm signing off now, though I'll try to keep an eye out in case there are any follow-up questions. I should also take a moment to thank my sponsors - I have the privilege of being funded to work on this project, by the UK's Engineering and Physical Sciences Research Council (EP/P029426/1), the Royal Commission for the Exhibition of 1851, and the University of Bath.

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RICHARD_BOWMAN R/SCIENCE

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I can imagine the potential benefit of offering devices open source for quick prototyping and ease of accessibility - but is there any oversight in the development of these technologies especially with respect to expected device classification?

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We've already had instances of devices making it to market in the U.S. via the FDA 510(k) pathway (traditional or special) that can potentially be used off-label.. do you foresee similar issues being more common place as access to 3D printers become more available and the price of medical devices continue to increase?

bambi_died

You're right, open source hardware in a regulated context like medical instrumentation is a relatively untested concept, but I'm pretty hopeful it can be useful. I think the first thing to say is that open source hardware can still be made, tested, and certified by a company. In order to use a device in a medical context you absolutely have to take care of things like compliance with regulations and quality control, so we are working with various companies that might be able to produce products for their local market, and handle quality control etc. as well as production. This doesn't stop people building the kit themselves, and/or customising it for different purposes - but I strongly suspect most healthcare organisations would rather buy their instruments from a company prepared to certify and/or support them.

A big difference between open hardware and proprietary designs here is that the company producing the instrument has incurred far lower set-up and design costs; that allows them to sell the devices more cheaply, and opens up the possibility of competition between suppliers.

I can certainly see open hardware getting used "off-label" and that's often a very good thing - ultimately the reason these designs are open is to make it easier for people to adapt and customise them for different purposes. Those modified designs probably should be approved separately for their new purposes though; making the design open absolutely isn't intended to circumvent legislation that's about keeping us safe.

As a parting shot, one of the reasons I'm keen on open source hardware for science is that it allows scientists to understand their equipment better, for example when looking for sources of error in a measurement. The same applies to medical devices - an open design can be more easily inspected by anyone who's interested, and I hope very much that people will look at the hardware (and software) designs we're making and spot things we can improve.

[edit - somehow I thought this post had been deleted, hence my second reply!]

I'm not exactly familiar with "open-source scientific and medical devices" but as a M.S. BME candidate with some exposure to regulatory science I find the inclusion of "open-source" with "medical devices" rather perplexing.

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Open-source hardware can be made by anyone, and that includes companies too. In the case of medical devices, our current thinking is that it would be produced and certified by a company - that's important for quality control as well as legal certification. Anyone (including other companies) is still free to use, improve, analyse, and customise the design, so the benefits of open hardware remain - but healthcare organisations will usually want to buy a product that has been made by a company that's prepared to support it.

I think of it in analogy to generic drugs - it's not that hospitals are setting up DIY chemistry labs to roll their own, but it makes it easier (and cheaper) for companies to create new products if they can start from a tried and tested design. The fact that the design is freely available should also keep prices down through competition.

Of course, a product that is intended to be customised can, will, and should be used for purposes other than what it was designed for. However, it's important to make the point that once you've modified it, it's no longer the product that was certified by whoever made it (and that's one of the reasons open source licenses are important). A certified medical device based on an open-source design will probably need to be very clear about what you can do to it without voiding that certification.

I'm looking over your designs for the OpenFlexure microscope. Assuming a community has access to a capable 3D-printer, what notable differences in price/material cost will they find for the positioning components versus a preassembled similar product?

adenovato

Mostly it depends what you compare it to! A typical commercial motorised microscope stage could cost £10-15k (or $10-15k). That will be faster and have a much bigger load capacity than the OpenFlexure Microscope, but it's the easiest way to get automated control of sample positioning. The mechanical bits of my design (i.e. not including the camera or optics) cost about £5-10 for the plastic, and another £2-3 for nuts, bolts, and elastic bands. The stepper motors are about £1 each (and you need 3) and the drive electronics can be built for £20-40, and cheaper if you were making any quantity. Of course that doesn't include assembly or running costs of the printer, but you could probably include both of those and still be comfortably under £50-100.

A more direct comparison might be between the OpenFlexure Block Stage and an equivalent product from an optics company. The cost of the plastic stage (including motors) is similar (£50-100 including someone's time to build it), and the commercial ones will be ball-park £1000 for a manual stage and maybe £3000 for a 3-axis motorised one.

As a general question, what technology hurdles do you face in the field of automating instrumentation? I assume handling optical components is difficult, but you know what they say about assumptions!

adenovato

I think the biggest headache I encounter when automating stuff is the need to cope with drivers for all the different bits of equipment. Usually automation in the lab involves integrating things together, so there's a lot of groundwork needed to get control of everything from a single, high-level script.

There are (expensive) commercial systems that can help a lot with this, like LabVIEW, but these days I've moved away from that, because a lot of the people I'm working with now can't afford LabVIEW licenses.

In terms of building automated instruments from scratch, one of the hardest things is knowing when things have gone wrong - detecting and fixing errors is pretty tricky, but super important as soon as you share a system. Going from an experiment that works most of the time for me, to an instrument that anyone can use without much training is a long and tricky process!

I see this work being more likely in developing/underprivileged places than in established labs due to a lot of various biases. Is that your intention?

sciencereader3455

That's certainly where a lot of the interest has come from - people without access to the usual scientific suppliers are often a lot happier to use something that looks homemade than folk in established labs with a lot of funding.

That said, my intention is to make something good enough that I can use it in my lab at Bath as well. I'm not going to put ThorLabs out of business any time soon, but there are a lot of experiments even in well-funded University labs where smart people do very boring things because automated microscopes are expensive. That's particularly an issue for PhD students, as their time is often considered quite cheap in comparison to automated equipment! I've already seen a few people use stages and microscopes I've designed for experiments in labs in the UK and Germany, because it's more convenient than using the more conventional kit, or easier to automate.

My original idea was to make equipment that would help PhD students and postdocs automate their experiments, though the focus has shifted a bit since thanks to some collaborators in Tanzania, and some really helpful input from Tech for Trade (http://www.techfortrade.org).

What's the costly and/or non-printable piece of a microscope, say to help diagnose malaria, that would hinder open source products like yours?

scienceaccount103040

The most expensive single bit is the microscope objective. You can spend quite a lot of money on that, though relatively cheap ones are available from China, in the region of £50. There are a few other key bits of non-printable kit (a couple of extra lenses, and the camera sensor) but the objective's most expensive.

I don't think that's a big hindrance; the objectives are fairly simple to get hold of even if they do cost money.

It sounds like there is a market for standardization of instrumentation communication protocols! What do you think?

scienceaccount103040

Absolutely. The trouble is figuring out how to do it! There are lots of projects where people have tried to come up with standard software frameworks for equipment, but I've not yet seen a project that has been adopted widely enough to be a true "standard".

There are a few low-level protocols like RS232 Serial or GPIB that are used by loads of equipment, but every instrument has its own command set - because unfortunately instruments are usually quite specialised. The really hard part is the next level up in the software stack - I'd love to be able to have a standard API for each type of instrument. For example, every spectrometer in my lab could be treated as a subclass of one abstract "spectrometer" class, so when I write my experiment code I don't need to worry about what hardware I'm using. However, that's a mammoth project that would need buy-in from a lot of people. I got involved in writing one such project, which is very useful in our lab, but (like many such projects) would need a lot of work to be useful elsewhere.

It's worth mentioning two promising projects though - micromanager, a system that interfaces a lot of microscope hardware with ImageJ, and OpenIOLabs, a company aiming to create open-source technologies to integrate everything in your lab together neatly and without too much effort.

I should really get my software into shape so it can be used nicely in micromanager! Currently it's all controlled by Python running on a Raspberry Pi, which is very open but not very connected to anything else.

What do you see as being the main advantages of open source hardware for established labs in places with good access to scientific equipment, and what are the main advantages in places where this access is very limited?

What do you think are the biggest opportunities, and challenges in creating more open source hardware for scientific applications?

septic_bob

There are quite a few advantages for established labs - I think the most immediate one is being able to automate things, and particularly being able to connect different pieces of equipment together. Partly that's a question of openness (many manufacturers lock down their software and make it hard to integrate different instruments together) and partly it's just that automated lab equipment can be really expensive. That leads on to parallelism; often, it's the availability of a microscope or auto-alignment stage that's the limiting factor; even if you can afford one, it would be useful to have 10 of them so you can run many experiments at the same time, or dedicate microscopes to different experiments so you don't lose time and effort swapping between configurations.

Also, I think reproducibility is an important thing to consider; if you make your experiment design fully open, it's much easier for other scientists to corroborate your findings, and/or figure out systematic errors. As we push towards "open data" and open sharing of research code, I think open hardware should be next on the list.

In places where access to expensive, commercial instruments is more limited, I think the advantages are roughly what you'd expect; it enables experiments to happen that simply aren't possible otherwise. My dream is that we'll be able to come up with some open-source instruments that are both good enough to use in high-level research in rich countries, and accessible enough that even labs with very modest resources can get them. Experimental science research and teaching is something that should benefit everyone, not just those rich enough to afford it.

I think some of the biggest opportunities come from making use of consumer-level hardware - sensors, lasers, microcontrollers, etc. are amazingly cheap and amazingly good - the challenge is putting them together in a reproducible, reliable way. That's why I've focused on getting the mechanics right for the microscope; in many ways, the mechanical frame is what enables all the various bits of cheap tech to work together and make a useful instrument.

A key challenge, as I see it, is keeping open source hardware in touch with the scientific mainstream. I really hope that in a decade's time, it will be normal to use (and, hopefully, to buy from instrumentation companies) hardware where the designs are open-source. That requires well-funded scientists in rich countries to opt in, and to share their custom designs openly. I think there are strong arguments for why we should do that, but we still have some way to go.

Do you envision a future where all instruments can be manufactured onsite by specialized printers?

sciencereader3455

Hmm, I'm not quite sure on that one! It is an appealingly Star-Trek-like vision of the future, but I think if it happens, it is a very long way away. Given that a lot of the component parts (sensors, microcontrollers, lenses) are quite inexpensive and very hard to fabricate in small quantities, I think it (currently) only makes sense to print the bits you can't easily buy. That usually ends up being the mechanical mounts to hold everything in the right place.

My vision of the future is a bit more modest (and hopefully a bit closer) in that what I'd really like is to be able to commission an instrument from a workshop (which might be part of my University or might be a company) by just pointing them at the open-source design. Then they can print, machine, purchase, assemble, or whatever - I get an instrument built to a well-tested design that's compatible with everything I want to do, but I don't have to build it myself. It's very much the "Digital Blacksmith" concept that Tech for Trade are keen on, where small companies (usually in developing nations) are able to produce things to order using open source designs.

How advanced a microscope could you realistically produce using 3D printing and readily available electronics? What sort of work could you do, and what would be beyond its capabilities?

septic_bob

That's mostly a question of how much you're prepared to spend on the optics! If all you have is a webcam and an LED, you can do basic bright-field microscopy, and maybe dark field or phase contrast with a bit of cunning. If you spend £1-200 on your optics, it's possible to have a "proper" microscope objective and illumination. That should be good enough to produce high-resolution images that you could use for malaria diagnosis, which are equivalent to what you'd get out of a normal lab microscope.

Customising the design to add in beamsplitters, for example to do fluorescence or reflection-mode imaging should be possible, and if you can use LED illumination that needn't be hugely expensive - perhaps another £50-100. Getting to more advanced techniques like confocal or structured illumination (which could produce 3D images) would be harder, but structured illumination at least might be possible using a micro-projector for a few hundred pounds. That's an experiment I'd love to do!

Some of the really high-end stuff, like localisation microscopy (PALM/STORM superresolution) requires fast, extremely sensitive detectors like electron-multiplying CCD cameras or photomultiplier tubes. That jumps the price up to many thousands, at which point the benefit of having printed your optomechanics is no longer so big!

Oh hai!

I work in medical imaging and most times the FDA locks all the functions that the vendor would leave open to the user. The few ones that are open for the final user get locked by the legal department of the hospital because of the liability concerns. I mean... you can't even install software security Patches on the console Windows 2003 operating system, let alone upgrade it.

How would an open source device even work? Who would be responsible? Who would certify it? How can you certify it if the user can modify it in any way?

lucaxx85

I think the answer is that, if you need to certify it, you also need to be clear that the certification only remains valid for a particular configuration or design. That might mean adding tamper indicators to software or hardware, so that it's clear when someone has modified an instrument. Open designs should make it easier for people other than the original manufacturer to repair or upgrade things, but they would then be responsible for making sure it complies with the relevant rules.

I think in the case of heavily regulated sectors like medical devices, the tweakability probably ends up being locked down before it gets to the end user - but it might give more freedom to e.g. a small manufacturer who wants to customise the product to integrate with a particular system. It should also make it easier to maintain legacy equipment where the manufacturer no longer exists, or no longer supports a product, by allowing third parties to pick up where they left off.

Thanks for making the Openflexure Microscope! I've printed one already (for someone else) and a second one is printing right now (for me) and I have a few questions...

The site/Github README has instructions for printing and assembly but almost *nothing* about how to actually use it. Is there any plans to provide, say, videos of the microscope in action and examples of using it to identify various pathogens? Some example images taken with the microscope would also be helpful. I couldn't find any in the Github repos or on the waterscope.org site.

Background: I wanted to try using this microscope along with some machine learning/OpenCV code to try to have it "learn" what certain pathogens look like so it can identify them automatically with some accuracy but without example images of actual pathogens there's no way that can happen. Is there a project somewhere that collects images of known positive and known negative microscopic images of various pathogens (that could be identified by such a microscope)? Even short (few seconds) videos of pathogens would be useful (if motion is an important indicator).

Are there any plans to include a mount/case for a Raspberry Pi to affix it to the microscope (or at least, a way to keep the two together in an organized, easily-transportable fashion)?

Thanks for doing this AMA!

Fun little FYI about the microscope I already printed: The first Openflexure Microscope I printed was for a local FIRST Robotics Lego League team who wanted to use it in their team project (which they found on Waterscope.org; this year's theme is Hydrodynamics). They got it mostly assembled but ran out of time before the competition (they switched projects at the last minute).

riskable

There's certainly an intention, if not concrete plans! It would be really nice to start a gallery of images taken with the microscope, and that is something I definitely should do in the future. That said, there are quite a lot of more general primers on microscopy available online, so I should probably collate links to those rather than duplicate everything specifically for my design.

You are right though - I should definitely add some sample images!

I'm not aware of any single project that collects lots of images like that, but it would be a really interesting thing to do. In fact, I'm currently starting a project that aims to do just that for malaria (where diagnosis is usually done by looking at a microscope image of a blood film, and you can see the parasites inside the blood cells). We'll be advertising for a postdoctoral researcher in computer vision to do just that sort of analysis. We also plan to share our (hopefully quite big) dataset of blood smear images for other researchers to use in the future.

The lack of a nice case that will integrate a Pi, a microscope, and optionally a motor controller and/or touch screen, is one of the biggest headaches with this project. We've now got a baseplate for the microscope that makes it easier to mount into a box, but a case that integrates the Pi is rising up my hit-list. That said, it would be a great first pull request for anyone interested in getting involved with development - hint hint!

It's always great to hear from people who've printed/built microscopes - do leave a build report (you can submit it as an issue on github, or add to the wiki) if you have time, and/or share some images if you have taken any!

Hi there!

Fellow physicist here. I used to work for a very large european center that deals with nuclear research. Then I switched to medical imaging. And I keep on seeing those that work there or in universities coming up with the most useless idea, that are generally 10 years behind what the industry already has, and that are extremely poorly engineered.

How do you prevent these risks in your project?

lucaxx85

The honest answer is that it's tricky! I try to keep in touch with what's available commercially, and to be clear (both within the team and when talking about the project) what it is about the work that's new and useful. Obviously this is not the first project to make it possible to automate a microscope - and if you buy an automated microscope from any of the big microscopy companies, it will be vastly more advanced. With the various printed instrument designs, I'm aiming to hit the sweet spot of performance that's good enough for a particular application, combined with a cost of production that's much lower than conventional manufacturing. I think that's possible, especially for low volume scientific applications.

There is also an element of being provocative here, though - by releasing open designs, what I'd love to do is challenge existing manufacturers to make their products better, cheaper, and more open. Given that one of my stated aims is to free up scientists from doing repetitive tasks themselves, it would be a serious own goal if I ended up turning PhD students into low-quality instrument manufacturers! Ultimately, the aim of this project isn't to put Zeiss, Leica or Nikon out of business, it's to make it possible to do a lot of automated microscopy, a lot more cheaply that it's done at the moment. We're already starting to see instruments that are easier to integrate with custom optics, for example, and drivers that are easier to use from your own software - and I think that is in part a response to scientists wanting to create, and often share, new instruments.

Dr. Bowman, What legal issues arise (patent and such) when developing/designing hardware with open source software. I am a senior EE major working on a couple of personal projects and haven't given it much thought other than keeping thorough engineers notes.

Samuwheel

I think it depends on which bits are open and which bits you want to keep secret. Pretty much all the commonly used open hardware licenses permit commercial use, so you'd be fine to sell hardware based on an open design. However, some of the licenses insist that derivative works are also shared openly (e.g. the CERN open hardware license that I've used for the microscope). Obviously open source software, and hardware designs, are in the public domain once they're shared, and so they can't be patented (at least in the UK) after that has happened.

Using open source software tools to design hardware probably doesn't have many implications though; while "derivative works" are often subject to the terms of a license, simply using a software tool to produce something is unlikely to have any legal consequences for your work. If you're going to make a lot of money out of it, though, it would probably be polite to give something back to the open-source projects that have helped along the way!

I should of course add the caveat that I am absolutely not qualified to give any legal advice, so if you've specific questions you need to find yourself an IP lawyer (or perhaps talk to your University's commercialisation people).

How about open source, 3d ultrasound? How possible is that?

rforney

I'm no ultrasound element, but given that ultrasound transducers are relatively easily available, I think it's a possibility. You'd need some pretty cunning software though, so it relies on finding folk with the right skills to put that together, who have time and inclination (or if they're lucky, funding) to share their work openly. And of course it would be subject to all the legal issues folk have raised above if you want to use it in medicine...