Transitioning from Academic Innovation to Viable Humanitarian Technology: The Next Steps for the OpenFlexure Project

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Abstract: Academic interest in designing medical technology appropriate for Africa continues to grow, with funding available for innovations that answer complex questions. However, there is significant engineering work required to realise the promised impact of an innovation, even when it is shared as an Open Source design for others to build on. With academic innovation more highly prized by journals, funding bodies and academic institutions, this results in split priorities, and can lead to a difficult balance between the humanitarian aims of the project and pursuit of novel research. We present the OpenFlexure Microscope project as an example of an innovative academic project pushing the limits of 3D printed instrumentation. The microscope is already undergoing trials for malaria diagnosis, but significant product development is still necessary to transition the project from a prototype to a certified *in-vitro* diagnostic device. In this paper, we consider the engineering work that is needed to move from prototype to product, and how best to structure this work to support distributed manufacturing across Africa. We highlight the need to focus not just on the necessary engineering, but also on documenting this work so it can be understood and reproduced by any potential manufacturer.

Keywords: Microscope, Product development, Local manufacturing

1. Introduction

There is growing interest and activity in the design of medical technology appropriate for the African continent [1, 2, 3]. The focus of this research is to create robust, accessible technology. The most robust and sustainable solutions are those that can be built, maintained, and repaired locally. Local manufacturing produces a long-term solution that ensures availability of spare parts and local service engineers. It is essential that institutions in the Global North that wish to participate in designing this technology co-design products not just with local users, but also with local engineers. Without the input from local engineers, it is impossible to understand the local manufacturing landscape. Any design produced without this understanding will likely require significant revisions.

Local manufacturing of medical devices is not without its challenges. In many nations, there are no established manufacturers of medical devices. As such, regulatory bodies often only have procedures in place to certify imported products rather than locally manufactured

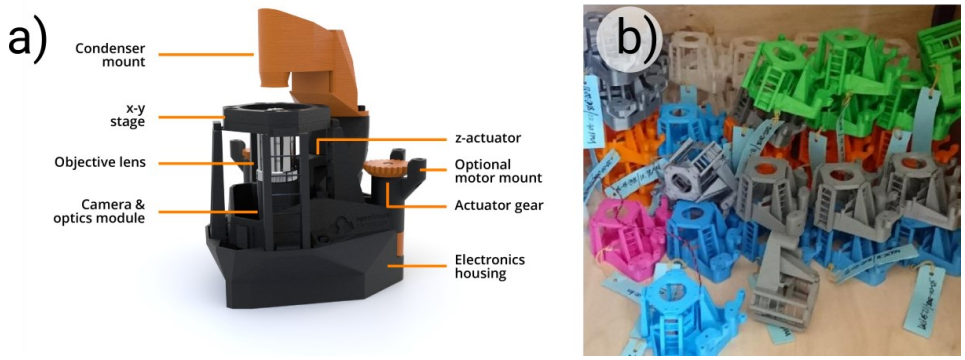


Figure 1: a) A labelled diagram of the OpenFlexure Microscope in a trans-illumination set up. b) A photograph of the microscope bodies produced in Tanzania as part of a baseline production run in 2018. a) reproduced from Collins et al. [8]. Copyright Collins et al. licensed CC-BY.

products [4]. These challenges are not insurmountable, but they require an investment of time to build the processes that are necessary for quality managed medical device production. However, for projects that are academically funded in the Global North, this requires a rethink of the established pathway from academic innovation to real-world product. The established pathway in countries such as the UK is to use patents to protect innovations, and then either to form a British company to invest in the manufacturing process, or to license the patent to an established manufacturer. That route precludes the ability to establish local distributed manufacturing of the innovation.

Academic funding agencies have established schemes to fund research that addresses global challenges, for example the Global Challenges Research Fund (GCRF) in the UK [5]. If projects that design technology for local production are to achieve their desired impact, then both funding bodies and academic institutions must consider how to support the transition from academic research project to viable certifiable product.

Academic projects regularly produce prototype designs, but this is only the beginning of bringing a product to market [6]. Design-for-manufacture, quality management systems, and high-quality technical documentation must all be produced. Expecting potential manufacturers to complete these remaining steps creates a high barrier for entry, even if the prototype design is well documented. If the goal is to establish distributed manufacturing across multiple locations, then these steps will need to be repeated by each manufacturer, creating a significant duplication of effort [7]. As such, we argue that this work must be done by, or at least be supported by, the original research project.

Having the original prototype design team continue with the development of a final product is ideal from many perspectives. However, relying on academics to do work traditionally considered as product development has numerous problems. This work may fall outside the traditional academic skill sets. It may be seen as not strategic by the academic, as this work may not lead to sufficient academic publications. Furthermore, funding agencies often see this work as either outside their remit or as less academically stimulating than earlier stages of innovation.

The fact remains, however, that if academically developed technology is to have significant impact on solving global challenges, then funding bodies must support technology projects not just from conception to prototype, but all the way through to sustainable deployment of the technology.

In this manuscript, we present the OpenFlexure Microscope as an example of a technology co-designed in UK universities, a Tanzanian engineering firm, and a Tanzanian health institute [8]. The motorised laboratory-grade microscope is capable of automated digital data

collection. The microscope can be manufactured and maintained in Tanzania, and can be used for applications such as malaria diagnosis. In this manuscript, we present the state of the project. We detail the ongoing technical work that is required to move from established prototype to final product. We also discuss progress towards establishing a quality managed manufacturing process that can be replicated across the continent with minimal duplicated effort.

2. Background

The OpenFlexure Microscope is a 3D-printed, laboratory-grade, automated microscope (Figure 1). The microscope is able to automatically scan a sample through a 12 × 12 × 4 mm^3 volume relative to the objective.

The microscope uses plastic flexure hinges to provide high precision translation. The main mechanism is printed as a single monolithic structure. The use of flexures rather than traditional dovetails removes the need for precision ground components, and the monolithic structure eliminates the need for the tight tolerances of components in a mechanical assembly. The precision of the microscope stage is derived from the symmetry inherent in the design, rather than the accurate sizing of components [9]. The microscope can be printed on an entry-level 3D printer, and relies on standard available components. This makes the microscope suitable for local manufacturing anywhere in the world.

In its standard configuration, the OpenFlexure Microscope includes a plan-corrected microscope objective, an onboard Raspberry Pi computer, and an Open Source custom motor driver. In this configuration, the microscope functions as a fully automated, general purpose laboratory microscope. As an Open Source project, the microscope is customisable for a range of uses and budgets. These options include lower cost builds suitable for education and hobbyist use, forgoing motorised control and using a webcam for imaging and optics. The microscope can also be modified for specialised techniques such as fluorescence [8] and super-resolution imaging [10]. While the microscope has been designed for adaptability, the core focus of the OpenFlexure project is microscopy for parasitology.

Manual optical microscopy is described by the World Health Organisation (WHO) as the "gold standard" for malaria diagnosis [11]. Current best practice involves manually examining a Giemsa stained blood sample under a transmission microscope with a 100× objective. A microscope with sufficient resolution, magnification and contrast allows the microscopist to count individual *Plasmodium* protozoa, the parasite which causes malaria. Advantages of this method of diagnosing malaria include that it can be performed at the point of care (POC), that equipment is versatile (can be used to diagnose other conditions), and the slides or micrographs can be stored to keep a record of the test. Crucially for areas in which malaria is still endemic, the cost also scales favourably – the price per test decreases with the number of tests, as the microscope is the most expensive part of the process.

There is a range of effective malaria treatments available, and if diagnosed early the prognosis is generally positive. Despite this, malaria continues to kill over 400,000 people per year worldwide [12]. The overwhelming majority of these deaths are in low resource areas, especially sub-Saharan Africa. The WHO identifies that microscopy is limited by the time required per sample, and the delay in results if diagnosis isn't available at the POC. Diagnosis also requires good technique, high-quality microscopes, and a trained, skilled, supervised technician, which further restricts the availability of reliable tests. Where malaria tests aren't

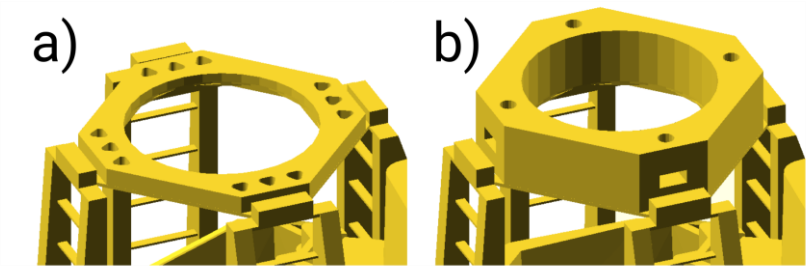


Figure 2: Rendering of the sample platform of the OpenFlexure microscope before (a) and after (b) modification. The thicker stage allows for steel nuts to be inserted into the stage. In previous versions, machine screws were tapped into trilobular holes that were easily stripped.

administered correctly, the WHO warns that "microscopic diagnosis risks becoming an unreliable tool that uses up scarce resources for doubtful results" [11].These doubtful results may lead to an incorrect diagnosis, the correct treatment being withheld, and valuable drugs being needlessly dispensed [13]. Inaccurate testing can also have social and economic impacts, as trust in healthcare professional decreases and already limited resources are wasted on ineffective treatment [14].

While malaria diagnosis has been the core application considered for the OpenFlexure microscope, it is designed as a general-purpose microscope for *in vitro* diagnostic use. The microscope could also be investigated for use in diagnosing other parasitic infections such as schistosomiasis, or for diagnostic techniques such as analysing pap smears.

As of December 2020, the OpenFlexure Microscope is a fully functioning prototype, capable of multiple imaging modes for a range of purposes. The designs and documentation are sufficient that the microscope has been reproduced and adapted by collaborators with varying levels of expertise and resources. However, in order for the microscope to reach its potential as an *in vitro* diagnostic device, it requires manufacturers to take it through medical certification. Before that can happen, significant product development is needed to transition the project from academic prototype into a viable product. Here we present the current state of this ongoing work.

3. Engineering a robust microscope

3.1 – Failure mode analysis

There are many differences between a prototype and a final product. One key difference is that, while a prototype must be able to function, it is not expected to be reliable for months or years of continuous use. While this allows rapid development of functionality, concentrating solely on functional development can significantly increase the number of changes that are necessary during the product development phase. Throughout the prototyping phase, we have been optimising the performance of the microscope so that it is sufficient for malaria diagnosis. We have always been mindful to ensure we are using manufacturing processes and components that are available in Tanzania. However, as we move on from a proof of principle and look towards medical certification, we must now consider the longevity of the microscope.

During prototyping, the main failure mode that has been considered is the degradation of components that deform when translating the sample relative to the microscope objective. The translation mechanism for the microscope relies on the bending of a plastic structure tensioned by rubber bands. Initially, the microscope used non-specialist rubber bands from

stationary suppliers. By changing to fluroelastomer (Viton®) O-rings, widely used for forming mechanical seals in the automotive and aerospace industry, we were able to improve both the longevity of the component and specify it more accurately. Fatigue testing of the microscope revealed that the 3D printed flexure hinges were able to run through approximately 30,000 cycles of the stage motion over several months before failure. However, this lifetime is severely reduced if poor quality materials are used for production. Surprisingly, in initial testing the threads on the A2 stainless steel actuating screws were the first components to fail. As the steel screw drives a brass nut, we would expect the brass nut to fail first. This highlights the need for a controlled procurement process to ensure component quality. It also demonstrates that we need to establish a maintenance schedule, to ensure that mechanical components are appropriately lubricated and replaced before performance degrades.

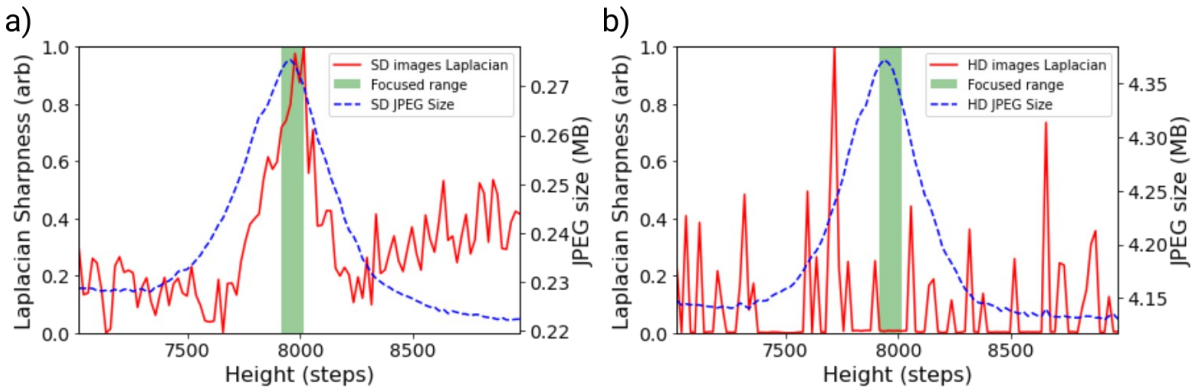
While attention has always been paid to the most obvious critical failures that would prevent the microscope from ever becoming a product, until recently we have not explicitly performed a failure mode analysis. Failure mode analysis is a systematic review of all possible failure modes for the microscope, scored for severity and likelihood. We are still in the early stages of completing a failure mode analysis for the microscope. However, the systematic nature of the analysis has highlighted the seriousness of certain issues with the design, helping us to readjust priorities.

3.2 – Stage design modification

An example of where our priorities were adjusted due to the results of the failure mode analysis was the recent redesign of the microscope stage. The current release of the microscope has a detachable 10 mm thick "sample riser" on the top of the *xy*-translation stage (see Figure 2a). This allows the microscope to be compatible with standard 45 mm parfocal length objectives, while also allowing compatibility with 35 mm parfocal objectives that predate this standard. Components screwed to this stage use holes tapped directly into the 3D printed structure. Due to the loose tolerances of 3D printers, correctly sizing this hole for tapping was unreliable, leading to the taps stripping the holes. Instead, trilobular holes are used to allow standard machine screws to self-tap into the stage. The drawback of this design is that, due to the minimal thread engagement, slight over-torquing of the screws can lead to the thread stripping.

While this simple design allowed for flexibility of the microscope during prototyping, failure mode analysis reveals that this design combines a severe failure with a common occurrence. The failure is severe, as the entire monolithic mechanism needs to be replaced to fix one stripped hole. The development version of the microscope has since been modified such that the stage is 10 mm thicker, allowing room for "nut-traps" (see Figure 2b), but removing compatibility with older objectives unless a specialised mount is designed.

This example, while apparently somewhat trivial, highlights the need for procedures that identify issues that are tolerable during prototyping, but must be fixed before a technology can be implemented. In the following section we discuss another issue, autofocus, in more detail. The reliability of the autofocus routine is essential for automated microscopy.



3.3 – Robust and reliable autofocus

As previously mentioned, the core application considered for the OpenFlexure Microscope is malaria diagnosis. When using a traditional microscope to analyse a blood sample for malaria, a microscopist will count the number of parasites in an area of the sample. The

Figure 3: The Laplacian and JPEG size sharpness metrics applied to a stack of 99 standard resolution (a) and full resolution (b) images of a zea seed section collected using a 40× objective. One motor step corresponds to a microscope objective movement of approximately 50 nm.

sample area checked is larger than the field of view of the microscope, requiring the microscopist to translate the sample. As the sample is translated, the microscopist may have to refocus the microscope. As the OpenFlexure Microscope is a motorised, digital microscope, it is able to automatically move and capture images at regular positions in a grid. This saves considerable time, but is only of use if the microscope can reliably refocus during sample scanning.

Our automated sample scanning is performed by generating a list of positions in the sample plane (*xy*-plane) based on the input scan parameters. At each *xy* position, the system captures a series of images with varying focus, achieved by translating the objective in the *z*-direction. We refer to a set of images in which the objective height has been adjusted in regular steps as a *z*-stack. For blood sample scans, each *z*-stack begins with the objective approximately 1–2 µm above the focal height and is scanned to approximately 1–2 µm below the focal height. The images in this *z*-stack are used to determine whether the image is properly focused.

The sharpest image from each *xy* position are then tiled to produce an image with a very large field of view and high resolution, far exceeding what can be achieved by any individual microscopic image. However, to perform a *z*-stack we must first identify the focal plane, and ensure that the central image of the *z*-stack is in focus. As such, an autofocus step before each *z*-stack is essential.

Two autofocus procedures are included in the OpenFlexure software. The first autofocus procedure takes seven images regularly spaced throughout a *z*-stack, with a range of approximately 100 µm. Each image is then assessed for sharpness using a modified 2D Laplacian filter, commonly used for edge detection [15]. In this method, each image is converted into greyscale before a Laplacian filter is applied to give a measure of rapid change around each pixel. Each pixel score is then raised to the fourth power. Finally, the mean of this value over the image is used to score the sharpness of the image. The image with the highest modified Laplacian score was taken to be the focused image, as hard edges and sharp features are indicators of an in-focus image.

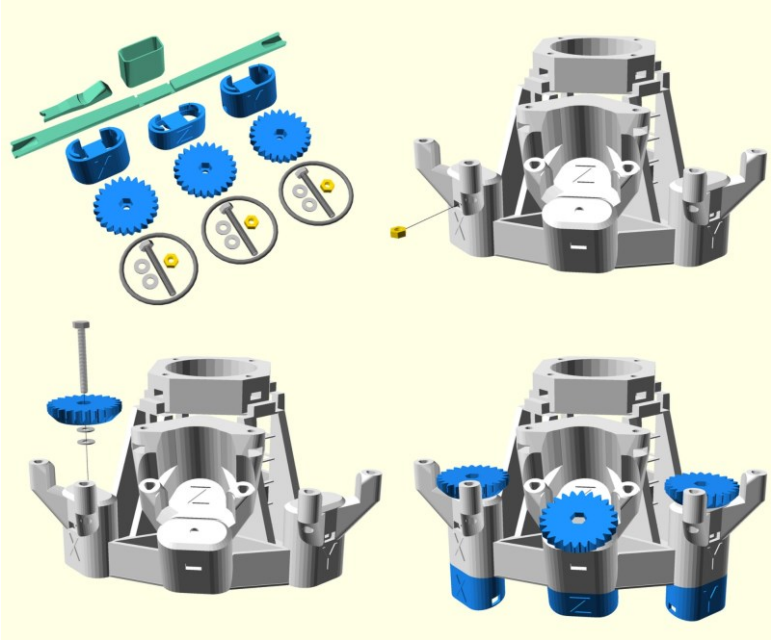


Figure 4: Examples of rendered diagrams that can be used to clearly describe individual assembly steps. These renders are automatically generated as the design is updated so we can ensure they remain up to date.

Once the sharpest image in the stack has been determined, the microscope returns to the *z*-position of this image. The process of capturing seven images, is both time consuming and only locates focus to the nearest ≈ 15 µm. Performing autofocus on an ipomoea root sample revealed that the procedure takes an average of 14.9 seconds, with a standard deviation of 1.0 s over 10 trials. As a typical blood sample scan records images at 100 *xy* locations, this procedure would delay results by over 24 minutes. Increasing the number of images in the stack to improve focus would delay the results further.

This delay was the motivation behind the development of an alternative reliable autofocus procedure with greater speed. The method utilises the MJPEG video stream that is used to show the user a preview of the current field of view. JPEG encoding uses the discrete cosine transform to describe small blocks of the image in terms of varying amplitude and spatial frequencies. Crucially, each block is described using a combination of the fewest discrete cosine functions possible. This means that out-of-focus images, which lack sharp features, are described using fewer cosine functions, lowering the image storage size. The key benefits of this metric are that, unlike the modified Laplacian, it is performed in real-time by the GPU (Graphics Processing Unit) on the microscope's onboard computer. It is also computationally 'free', as the MJPEG stream is already being created for the live preview.

By tracking the JPEG file size as the objective is smoothly moved through the focal point, a peak sharpness can be identified. As the sharpness is continually tracked during a single movement, this considerably increases the speed of the autofocus. Ten trials of this fast-autofocus routine took an average of 4.1 s with a standard deviation of 0.4 s. For a 100-location scan, this reduces the total time spent on focusing from over 24 minutes to under 7.

To assess the reliability and performance of these two methods of determining sharpness, we recorded 99 image *z*-stacks of a *zea* seed section. The distance between each image in the stack was 20 motor steps, or approximately 1µm, as one motor step corresponds to an ≈ 50 nm movement of the microscope objective. An example of these sharpness plots is shown in Figure 3. The identified focused area was judged manually by examining the images of the *z*-stack, and corresponds to a focused range of approximately 5 µm. We note

that this is larger than the ≈ 1 μm depth of field [16] calculated for the 40× objective (0.65 NA) used in this test. This is due to the finite thickness of the sample, the bright field imaging process, and the subjectivity of determining when an image is in focus.

Five criteria are used assess the performance of a sharpness metric [17]. These include the how accurately the sharpness peak is aligned with the most focused image, and how narrow the peak is. Three further criteria score the number, size, and distance to secondary peaks. Although it can be argued that only the accuracy is important, the other criteria indicate how reliable the sharpness metric is likely to be when applied to other samples. From Figure 3, we see that for standard resolution images (0.5 megapixels), both methods are approximately as accurate. The JPEG method has a wider peak, but the peak is smooth and free of secondary peaks.

The JPEG method remains reliable for full resolution (8 megapixel) images, whereas the Laplacian method fails entirely with multiple individual peaks, each outside the focused range. This behaviour was expected, as the Laplacian sharpness measure is highly sensitive to noise [18]. At this image size, the resolution of the image is greater than the resolution of the optical system, increasing the effect of noise. The Laplacian is also dominated by localised failures in a capture. Despite typically being only a few pixels in an 8 MP image, the contrast provided by these failures dominates the overall Laplacian score. As JPEG encoding is performed on small blocks within an image, the effect of a localised failure is restricted, making the JPEG sharpness metric more resilient to capture issues. As such, we conclude that the JPEG size metric is not only quicker than the Laplacian, it is also more reliable.

OpenFlexure autofocus procedures use the curve of sharpness against position in z to estimate the movements required to position the objective at the focal length from the sample. Due to backlash and the slight non-orthogonality of movement axes, this must be done in as few moves as possible. To prevent overshooting and needing to change motor direction (introducing uncertainty in the position), intentional undershooting and sharpness monitoring are used. Parameters such as the range to scan, spacing between images and order of movements need to be chosen to maximise reliability and speed. The software must also assess if the focus procedure was successful, and decide its next task accordingly.

It is important to ensure that users are aware of the limitations of different sharpness metrics. Laplacian sharpness is sensitive to noise and capture failure, whereas the JPEG size metric will fail on very sparse samples. As the blood smears used in malaria diagnosis are densely populated with blood cells, this JPEG algorithm should be robust. However, as the OpenFlexure Microscope is designed as a general-purpose laboratory microscope, it may be used on other samples that are considerably sparser. This further highlights the importance of providing multiple sharpness metrics, automatically assessing the success of the focus procedure, and providing sufficient documentation and training for users.

3.4 – Documentation

Another key change as the OpenFlexure project begins to mature is the proliferation of documentation. As an Open Source project that has always shared designs and encouraged other academics and hobbyists to use and improve the design, the microscope design has always been accompanied by documentation. This “documentation” was largely in the form of assembly instruction. However, the same documents also detailed why parts were designed and assembled as they were, along with different ways the microscope could be modified.

As the microscope moves towards production, it is essential that the assembly instructions provide a clear, simple, step-by-step procedure that can be followed. These steps will be augmented with quality assurance procedures where our failure mode analysis identifies they are necessary. However, the documentation on why the parts were designed that way remains important, as all potential manufacturers need to be able to understand how the microscope works and why design decisions have been taken. Otherwise, they will be unable to fix or improve the design at a later date. This is of particular importance in the case of the microscope, as the required quality management system medical device manufacturers must follow[19] requires this understanding, and continual monitoring and improvement of the design.

The next step of the documentation is to generate separate assembly instructions for each variation of the microscope, and document the reasoning behind the design. These documents, however, must remain consistent and linked. To aid with this, we have spent two years writing a documentation system that allows multiple variants of the documentation use the same data, reducing duplicated information and allowing automatically generated bills of materials [20].

We have also begun creating detailed renderings of the assembly process that are automatically generated each time the design is updated (see Figure 4). This prevents the instructions becoming confusing when assembly photos were taken with old versions of the design, without needing to take a complete new set of assembly photos each time the design changes. Alongside this, we also need to compile other documentation such as the maintenance schedule (also informed by the failure mode analysis), a user manual for the microscope, and documentation for the software.

The microscope source code and design process also require further documentation. The microscope geometry itself is programmed in a computational solid geometry language called OpenSCAD [21]. The software for the microscope is written in Python and Javascript. All of this code must be documented well enough that any manufacturer can continue to develop the product and support customers. We are currently going through the process of improving the readability and documentation of the codebases associated with the project. Our electronics (such as the motor driver) are produced in yet another tool, KiCAD. Finding a way to integrate documentation across all platforms and tools used is an ongoing process.

As well as the design and code itself, much of our workflow requires documentation. For example, the project makes heavy use of Continuous Integration. Continuous Integration is a process where scripts can automatically be run in the cloud whenever code is changed. We use this to automatically generate the operating system for the microscope, release software updates, generate the final CAD models for printing, render the assembly diagrams, and even compile the final documentation. Cloud automation reduces the need for local dedicated hardware for computational tasks such as compiling code. It allows us to separate the design itself from the generated manufacturing files. This limits the data usage required to contribute to the project, as only design files need to be uploaded, and contributors can choose which types of file to download. This automation saves us considerable time, allowing a small team to maintain a large project, but it also represents a significant body of knowledge that could be lost if it is not properly documented.

4. Discussion

Improving access to diagnostic technology requires more than making diagnostic instrumentation available. Spare parts, trained local technicians and the correct consumables

must also be available. Open source hardware can help to solve this by enabling local businesses to meet these needs, rather than relying on imports with unreliable supply chains. At the same time, establishing the manufacture of high-value goods such as automated microscopes in Tanzania helps to build a new sector of the economy, contributing to economic development by creating highly skilled jobs and training workers to fill them.

As the microscope is designed for diagnostic use, a business model must be established to ensure that local production is sustainable. More work is needed to better quantify the demand and budget available for diagnostic microscopy, and the estimated cost of regular maintenance or local service contracts. The viability any business model will depends on the cost of the microscope. The microscope has a parts cost of approximately $200, however the final costs can only be estimated once the costs of labour have been factored in. To estimate labour costs, we must better understand the overhead associated with medically certified production.

As we have detailed above, there is significant ongoing work for the OpenFlexure project to move from an academic prototype to a medical device. Systematic assessment of the modes of failure, and design improvements to make the microscope more robust to long-term sustained use form part of this work. However, documenting this process so that the institutional knowledge of the design can be shared with all potential manufacturers is as important as the engineering work itself [7]. For manufacturers to produce a certified medical device, they must be able to demonstrate that their quality managed production addresses these potential failures. It takes significant time, training, and investment to build up these skills in local manufacturers. Additionally, the regulatory bodies themselves in many countries will need to invest in new procedures to assess locally manufactured rather than imported medical devices.

Medical device certification is granted for a product, not just for the design. Crucially, this means that a manufacturer's procurement, assembly, manufacturing, and quality control procedures are all assessed as part of certification. As such, manufacturers themselves are liable for the final product, and are expected by a regulator to have the necessary understanding and expertise to assess, quantify, and mitigate potential issues with the product. While the open source license of the OpenFlexure microscope gives any manufacturer the legal rights to use the microscope design without further contracts with the original design team, it does not preclude the opportunity to enter into contractual agreements [7]. It may transpire that manufacturers would prefer to contract some of this ongoing design review, and hence liability, back to the original designers. These options will be considered as we progress with medical certification.

The key bottleneck to establishing production is not engineering work, but establishing a working relationship between all key parties, from designers and manufacturers to clinicians and regulators. We advise any project to establish these relationships early and to make a conscious effort to keep as much of the project work open and available to all stakeholders. Open collaboration builds trust and ensures that no party's expertise is excluded from the earliest discussions. However, it is important not to underestimate the difficulty of efficient open collaboration, and the time investment required to ensure work is available and understandable.

5. Conclusion

As demonstrated in previous publications [8], the OpenFlexure Microscope can function as a high-performance, laboratory grade microscope. In addition to the diagnosis of malaria and

other infections, it has applications in education, academic research, and outreach. However, a significant body of work is still needed to transition the project from academic research into a medical product. The difficulty of this transition is well documented. The stage of development between basic research and product launch is colloquially known as the "Valley of Death" due to the number of start-up companies that fail at this stage [22].

In the context of humanitarian technology, particularly technology design for local manufacturing, it is important to consider who should take the risk of taking a product through the "Valley of Death". In the case of the OpenFlexure Microscope, our funding comes from the GCRF, which forms part of the United Kingdom's budget for development aid. As such, we argue that this burden should also be supported by the UK or other countries in the Global North, rather than be offloaded on those in the beneficiary country.

While we have successfully secured a further year of funding for product development toward certification, the question remains on which institution is best placed to perform this development. As we have shown in the work above, there is not only a significant body of work to be completed, but a significant amount of project expertise that needs to be transferred. However, if the product development is performed at a university, this can be detrimental to the careers of post-docs and PhD students working on the project, as this work is unlikely to lead to the high profile publications required by academic employers. As the design is aimed local manufacturing in Africa, it is also hard to establish a business model for a UK business to take on the risk of product development.

We conclude that for the development of academic research into locally manufacturable humanitarian technology to be sustainable, funding agencies must have a plan to support ongoing development. Furthermore, it must be recognised that currently the most strategic decision for a researcher is to move to a new project after publication, rather than to invest time into further development. Institutions must do more to ensure that those focusing on impact driven research are not hurting their career prospects. Impact driven work rarely results in high profile publications, despite the coverage the same projects get from the highest profile journals [23, 24].

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