Schistoscope

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Agbana, Temitope; Van, G. Young; Oladepo, Oladimeji; Vdovin, Gleb; Oyibo, Wellington; Diehl, Jan Carel

DOI
10.1109/GHTC46095.2019.9033049

Publication date
2019

Document Version
Final published version

Published in
2019 IEEE Global Humanitarian Technology Conference, GHTC 2019

Schistoscope: Towards a locally producible smart diagnostic device for Schistosomiasis in Nigeria

Temitope Agbana
Mechanical Engineering
Delft University of Technology
Delft, The Netherlands
T.E.Agbana@tudelft.nl

G-Young Van
Industrial Design Engineering
Delft University of Technology
Delft, The Netherlands
G.Y.Van@tudelft.nl

Oladimeji Oladepo
College of Medicine
University of Ibadan
Ibadan, Nigeria
ooladepo@com.ui.edu.ng

Gleb Vdovin
Mechanical Engineering
Delft University of Technology
Delft, The Netherlands
G.V.Vdovine@tudelft.nl

Wellington Oyibo
ANDI
University of Lagos
Lagos, Nigeria
woyibo@unilag.edu.ng

Jan Carel Diehl
Industrial Design Engineering
Delft University of Technology
Delft, The Netherlands
J.C.Diehl@tudelft.nl

***Abstract*— Schistosomiasis is a treatable and preventable neglected tropical disease of Public Health importance affecting over 250 million people worldwide while Nigeria is one of the high burden countries. Currently available diagnoses are cumbersome, low in sensitivity and not field-adaptable given the high skill required that are not available in the rural settings where the diseases are majorly prevalent. Democratizing access to diagnosis with a rapid, easy-to-use, accurate diagnosis is critical in currently stepped-up control, pre-elimination and elimination strategies for urinary schistosomiasis. In this paper, we describe the design process of a low-cost smartphone-based microscope for rapid diagnosis of urinary Schistosomiasis.**

Field research conducted in Nigeria with the active involvement of key stakeholders in the research and development (R&D) process validated our assumptions and enabled the development of our proof-of-concept into a working prototype in three iterative designs steps. Through this design process, we investigated the local development of technical optics for good quality imaging and explored the simplification of sample preparation techniques using commonly available materials. Starting from the first iteration, the output of each design step was used as the input to the subsequent iterations to optimize our system design.

Insightful results and input from the field demonstrated that an adaptive design approach was needed to facilitate the rapid development and deployment of point-of-care diagnostic devices for use in low-resource settings. It is our goal that these devices will be locally manufactured in Nigeria to expand access to the test given her huge population and high disease burden, quick repairs, and easy maintenance on the field.

Keywords*— *Neglected tropical disease, schistosomiasis, global health, diagnostics, local production, technical optics, algorithms, artificial intelligence, Nigeria

I. Introduction

A. Schistosomiasis

The neglected tropical diseases (NTD) are a group of disabling, chronic diseases that are prevalent in tropical and subtropical, resource-constrained areas with poor sanitation and weak health systems [1]. One of these NTDs is Schistosomiasis, a water-born parasitic infection which is transmitted through contact with the vector, snail-infested water bodies during routine domestic, swimming, household, agricultural activities and wadding across streams/rivers.

It is estimated that around 250 million people are currently infected by Schistosomiasis and 779 million people are at risk [2]. The infection results in impaired growth and development, diminished physical fitness and decreased neurocognitive abilities [1, 3]. Schistosomiasis affects especially the poorest of the poor and it is prevalent among people living in rural, deprived urban or peri-urban settings. About 80% of the yearly infections are among the rural dwellers in tropical Sub-Saharan countries where access to available diagnostic tests is limited [4-7]. These populations typically have low socioeconomic status, inadequate sanitation provision with limited access to clean water [2].

There are three major species of Schistosoma; *Schistosoma haematobium*, *Schistosoma mansoni*, and *Schistosoma japonicum [8]*. We focus on *Schistosoma haematobium* (S. haematobium) in the first phase of our project because it is the most prevalent among our target population. Detection of *S. haematobium* eggs in the urine sample of an infected patient by light microscopy is the standard method of diagnosis.

B. Diagnostics gap

The WHO gold standard for diagnostics of S. haematobium relies on microscopy examination of urine samples prepared by filtration, sedimentation or centrifugation [1]. The availability of conventional microscopy in remote or rural communities is limited by high cost, bulkiness of equipment, shortage of required expertise and lack of required maintenance skills & parts [11]. Also, the manual microscopic examination of the filtered urine sample is time-consuming and prone to human-error [1, 11]. Urine filtration method requires membrane filters which are expensive and are not commonly available at point of needs. In rural areas, the existence of tremendously erratic

978-1-7281-1780-5/19/$31.00 ©2019 IEEE

power supplies precludes the deployment of centrifuges. Furthermore, microscopy is cumbersome and requires highly trained personnel and therefore reduces the opportunities of deploying diagnosis for community surveillance as an aid of tracking the progress of control implementation and reporting.

Safe and effective medication, praziquantel, is commonly available for treatment [9]. However, accurate diagnostic techniques for schistosomiasis is hugely underdeveloped and remains a critical challenge though reliable diagnosis is key for (early) treatment. Severe reduction in the prevalence and intensity of infection is achieved by large scale administration of praziquantel to school-aged population and high-risk adults through the mass screen-and-treat program [10]. Besides the urgent need for treatment of infected patients, a rapid and easy-to-use test device with high performance is also critical for the successful and implementation of control and elimination strategy. To ensure that national targets of the control and elimination program are met, there is a need for more accurate mapping of the disease and the institution of appropriate case detection and treatment paradigm. Consequently, a field adaptable diagnostic test that fits the capacity of majorly community trained personnel will not only provide access to diagnosis and reporting in the community but also enhances the understanding of the distribution of Schistosomiasis and help to guide program decisions for mass drug administration on a large-scale [2].

Based on all these limitations, there is, therefore, an urgent need for the development of new, reliable, sensitive, low-cost, and easy-to-use diagnostic instruments for the detection of S. haematobium infections in resource-limited communities.

C. Technological developments

Hand-held digital microscopes and cellphone-based microscopes are promising alternatives for diagnosis of Schistosomiasis. Rapid progress in optical and computational processing technologies has resulted in, sufficiently sensitive low-cost diagnostics for use in low-resource settings [12].

According to field reports, their portability makes them suitable for use outside of typical lab-setting [1, 3, 7]. Recent studies have introduced novel diagnostic approaches with innovative image-capturing techniques for applications at the point-of-care [1, 11, 12]. Integrating smart algorithms to automate the detection and quantification of *S. haematobium* eggs in samples will drastically reduce human intervention while increasing the sensitivity [12].

The benefit of digital microscopy compared to light microscopy includes the option to share real-time digital healthcare and location data for mapping purposes for control programs. The principle of digital microscopy is the starting point for the development of the *Schistoscope* as described in this paper.

D. Challenges and opportunities with digital handheld microscopes

Despite a wealth of technological innovation in this field which meets many technical and medical criteria, there remain key challenges in implementing mobile-microscopy devices in resource-constrained environments [6]. We shortly discuss three of the current challenges as well as opportunities we foresee to overcome them.

1) Technical optics

Cellphones combined with glass ball lenses have been reported in [6]. This cellphone-based microscope provides relatively poor image quality due to the inherent aberration of the optics and the limitation posed by the numerical aperture. Furthermore, the limited field of view (FoV), results in the need for multiple measurements, which reduces the sensitivity and specificity of the diagnostic instrument [13]. A method which replaces the ball lens with a reversed phone lens has shown promising results. It provides a large field of view (the entire sensor plane), and an improved resolution.

An ideal diagnostic instrument should be integrated with an efficient Artificial Intelligence (AI) algorithm which enables automated detection and estimation of the eggs in a registered image. A desired feature of the AI algorithm is that it must be implementable on low-profile digital signal processors. To realize this, methods which drastically reduce the computational complexity must be investigated.

2) Complex sample preparation

There has been comparatively little work done on simple, low-cost, laboratory-free means for microscopy sample preparation. In contrast to centrifuge methods that concentrate urine for parasite detection, filtration is a much more simplified method. According to the WHO Microscopy standard recommendation, 10 ml of urine sample should be filtered using a disposable polycarbonate membrane of pore size 12μm. Despite the simplicity of the filtration technique, the cost and availability of the filter and its holder limit its use in rural areas. From practical interactions with stakeholders on the field, filters and filter holders are imported and are delayed due to logistic reasons in most cases. Solving the filter availability challenge will enhance and facilitate the use of mobile microscopy in remote settings [6].

To circumvent this limitation, a research group attempted urine filtration with towel papers. Egg detection was barely possible due to background noise [14]. In our attempt to propose a solution as well, we investigated the use of coffee filters. Results were not useable due to the poor signal to noise ratio.

Finally, a locally sourced chiffon material with a pore size of 18μm was identified. The material filters the urine and the eggs were clearly visible when examined with a cell-phone based microscope in our lab. The conflicting periodic background structure, however, reduces the capacity to automatically detect the eggs in a registered image.

Therefore, we decided to explore computational methods to remove the structured background pattern of the material and enhance easy and quick detection of the S. haematobium eggs in the residue. The success of the proposed filtration technique, will reduce the cost, eliminate the scarcity of filtration material and simplify the entire sample preparation procedure.

3) Local production and maintenance

Most handheld microscopes, as well as the applied filters (for sample preparation), require sophisticated production facilities, which are not readily available where they are needed the most. Due to an enormous logistics effort required, the diagnostic devices are expensive, scarce, and difficult to maintain (due to lack of spare parts and required technical skills) at the point of need. This is critical in the provision of access and opportunities for engaging other diseases when local production is explored. Most NTD diagnostics and currently produced from non-disease settings and this relies heavily on overseas importation that further reduces cost at the point of use. The fragile economies of most of the poor countries whose source of revenue is on import duties and poor operational shipping processes would drive up the cost and make products inaccessible or expensive. Land-locked, Schistosomiasis endemic countries would also have to pay more for the devices due to the extremely high cost of shipping.

Mass production of components for the consumer electronics market in recent past has enabled the fabrication of low-cost, effective and portable digital imaging devices [1]. Manufacturing these devices by using locally sourced materials could reduce costs as well as improve maintenance due to the general availability of spare parts in the target areas.

Integrating this with innovative manufacturing pathways [6], we can overcome import dependency and unnecessary long value chains. Additive manufacturing technologies like 3D-printing offer new opportunities to set-up local production facilities which can supply devices and spare parts in the local context.

We envisage that once these challenges are addressed, portable digital microscopy could provide high quality diagnostics at the point-of-need. It will also provide timely information on the distribution of disease, thereby enhancing treatment, control, surveillance, and elimination of NTDs at the point of need [6].

II. Research Setup

To realize a decent digital microscopy system, we focused on three main challenges: (1) Optimization of the technical optics, (2) Simplification of the integrated sample preparation method and (3) Local production (as starting point for our project named Schistoscope):

*To develop a **digital microscope** which offers an **integrated diagnostics solution** (sample preparation and diagnosis) with the support of a **smart algorithm** (for detection and quantification of the S. haematobium eggs) which can be produced and maintained in Africa (use of **locally available components and 3D-printing**). Schistoscope will be shared through an **open-source platform** (to scale up).*

At the start of the project, we created a short movie to communicate the current health impact of Schistosomiasis, the lack of proper diagnostics, and the solution direction we envisioned https://vimeo.com/288035778. This movie also enabled a shared vision (see Fig. 1) within the design team.

Fig. 1. Screenshot of Schistoscope kick-off movie.

A. Field research in Nigeria

Nigeria is a context in need of Schistosomiasis diagnostics for direct treatment as well as for control and elimination programs. The country is of particular interest because it has the largest number of people living in Africa with NTDs. It ranks first globally in the number of people infected with schistosomiasis with 29 million infected and 101 million at risk [15]. According to Hotez et-al, only 6% of the population receives access to praziquantel for the treatment of schistosomiasis [16].

Two specific Nigerian Universities were approached: The Faculty of Public Health of the University of Ibadan for its expertise in understanding the local healthcare system, and the Department of Biomedical Engineering of University of Lagos for its expertise in digital health technologies and distributed manufacturing. The ANDI Centre of Excellence for Malaria Diagnosis Centre and Tropical Diseases Research Laboratory of the College of Medicine of the University of Lagos provided advice on the medical procedure and testing with the real-time sample.

B. Design approach

Even though a wide range of digital diagnostic devices has been developed for low-resource settings, very few of them have been successfully adopted by local healthcare systems. Balsam et al [12] for example mention that many modern and emerging diagnostic technologies are not affordable or compatible with the needs and conditions found in low- and middle-income countries. Likewise, Engel et al. [17] conclude that lack of end-user involvement in research and development, limited understanding of clinician, patient, and healthcare system behavior and insufficient test evaluation in target settings complicates the development, adoption, and scale-up of advanced diagnostics in low-resource settings.

To develop a new diagnostic device which matches with the local healthcare context and successfully become adopted, it is crucial to engage with stakeholders in an early stage. Conducting frequent experiments not only in the laboratory but also in real-world settings is critical for successful implementation. Based on these insights, we ensured two field visits to Nigeria within the six months timeframe of the project (see Fig. 2) from September 2018 to February 2019. As the project was executed as a part of the Master course (Design

project XL), the duration was initially set as one semester which is 6 months.

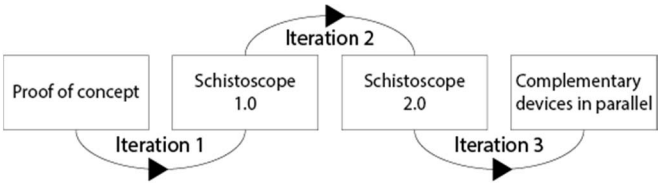

Fig. 2. Iterative design process characterized by experimenting and frequent field research

For the design process, tools and methods as described in the Delft Design Guide [18] in combination with the framework for the holistic contextual design for low-resource settings [19] were applied. An iterative approach with multiple planned experiments was set out to develop the three consecutive Schistoscope concepts: Schistoscope 1.0 at the start of the project, Schistoscope 2.0 after the first field visit, and the further development in key directions emerged.

C. Methods

Our field research was executed (i) to gather data to elicit user- and context-requirements within the local healthcare system and, (ii) to validate and further improve the functionality of the system and technical specifications as well as the local manufacturability.

To realize the goal of the first objective, we conducted expert interviews, organized focus group meetings, and staged system demonstrations with the potential users and stakeholders in Ibadan. For the second objective, we emphasized practical experiments using the prototypes in the local setting. We also organized iterative co-design sessions with Nigerian biomedical engineering students and engineering experts in Lagos.

During the first field visit, 12 expert interviews, 2 focus group sessions, and several co-creation sessions were held. The second field trip involved sample testing in the laboratory and peri-urban setting, and a range of discussion and co-creation sessions.

III. Results

Feedback from potential stakeholders was promising as our proposed device was positively perceived. They shared the idea of the fact that the simplicity of the device will make it easily adopted by the primary healthcare workers.

During each design iteration, the Schistoscope was adapted to become a better fit with the local healthcare system. It is perceived to be more specific to the end-user and matches with the locally available materials, components, and manufacturing methods.

The intention behind the initial design choices was to ensure more frugality by simplifying the device and using low-cost, locally sourced materials.

The first iteration (Section A) describes the trade-off between simplicity and standardization. Since our device will be used for medical diagnostics, diagnostic testing must be compliant with the WHO standard procedure and protocol.

In section B, we describe the development of the second prototype which demonstrates compliance and standardization with WHO protocols. In this phase of development, we discovered some basic challenges related to the technical specification of the optical instrument. Also, we realized that the local capacity of 3D-printing is still at a very early developmental stage making local manufacturing with 3D-printing more challenging than we envisaged. Finally, from field sample testing, we observed that urine filtration with local filtration materials did not produce a satisfactory result.

We report our findings in the following section and used the obtained insights to optimize our system design. Further details will be described in section C.

A. First iteration

The first design iteration started with developing a technical demonstration of the concept as shown in Fig. 3.

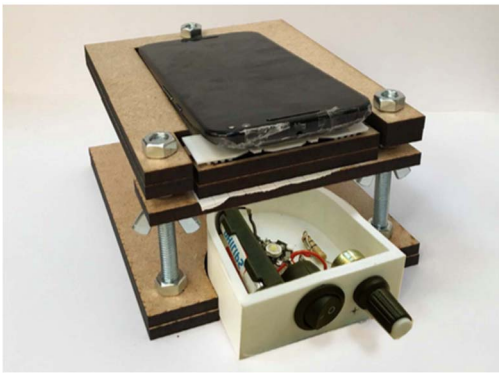

Fig. 3. A technical demonstration of concept, Schistoscope 1.0

The initial assumptions were quickly translated into a physical model ‘Schistoscope 1.0’ to represent the conceptual idea. The Schistoscope 1.0 is characterized by:

1) Optimization technical optics

A smartphone Moto X-style with sensor dimensions of 5.99 mm x 4.5 mm and a pixel size of 1.12µm was used. We realized the appropriate magnification and resolution by aligning a reverse phone objective lens with similar focal length (4.61mm) to the lens and camera module of the smartphone (See Fig. 4). The main framework was made with wood, while the lens mount and sample holder were 3D-printed. By vertical translation of the smartphone, the optical focal plane is determined. The illumination comes from the bottom of the frame.

After the acquisition of a focused image, the integrated algorithm is activated to detect and quantify the Schistosoma eggs in the sample. The software application indicates the number of eggs per sample and therefore provides an estimate for the infection load.

Fig. 4. Reverse phone objective lens added to the camera module

2) Integrated sample preparation

To simplify the sample preparation process, the filtration-technique was our preferred choice due to local availability and low cost of material. We explored both nylon and chiffon filter materials with a pore size ranging between 18 and 36 microns. The filter material was cut into the size of dimension 10 by 10 mm, and fixed on a designed 3D-printed sample holder. The sample holder is directly located in the sample plane of the system for quick examination using the mobile phone.

3) Local production

For the first prototype, the main body was made with laser-cut MDF (Medium Density Fibre). The filter holder and the illumination case were 3D-printed with an Ultimaker 2+. The adjustment of the focus is controlled by standard nuts and bolts (See Fig. 3).

B. Field research I

The aim of the first field research was to introduce the concept of digital microscopy to the local healthcare context and to test the envisioned diagnostic procedure.

In general, the concept was positively evaluated for its potential functionalities and ease of use for the healthcare workers at the primary level with a minimal amount of training. A range of constraints such as unstable power supply, bumpy roads for transportation, and lack of resources to sterilize the device properly was identified by the local stakeholders. The insights gained from the three design challenges in this phase generated more context- and user-specific specifications for the second design iteration which will be described in detail.

1) Optimization of technical optics

The outcome of the system design in phase 1 did not provide the required stability and accuracy needed for sample alignment due to the simplification of the system design and the wooden material used to fabricate the frame. The accurate vertical alignment of the sample is essential for the acquisition of in-focus image of the sample. The choice of the smartphone for optimal optical performance was reconsidered. Familiarity of the smartphone interface, flexibility in its user flow and interface design which will lower the usage barriers to the healthcare workers was critical to design choices in this phase. However, an observed limitation of the smartphone was the short battery life. Therefore, an alternative solution for power supply was necessary. The possibility of using the smartphone for other irrelevant purposes was a major concern. To tackle that, customizing the smartphones and ensuring limited functionalities was our only option. Since the price of the smartphone was rather considered too high, inexpensive local phone brands were recommended.

2) Integrated sample preparation

The customized filter should comply with the medical standard. Proving the consistency in performance will be a challenge if we want to develop the customized urine filter with local sourced materials. Another major problem with the proposed locally sourced filter was the difficulty of tightly stretching the material over the 3D-printed sample holder (See Fig. 5).

Hence it was difficult to realize an optimal image quality. From field interaction with stakeholders, we discovered that ordering WHO recommended filter was possible through online from the warehouse in China. It was interesting to discover that the filters could arrive in the country within 48 hours. A common challenge with the standard filter compared to our proposed locally sourced filters however, was the fact that the standard filter has a larger surface area making it difficult to realize complete diagnosis in just one field of view.

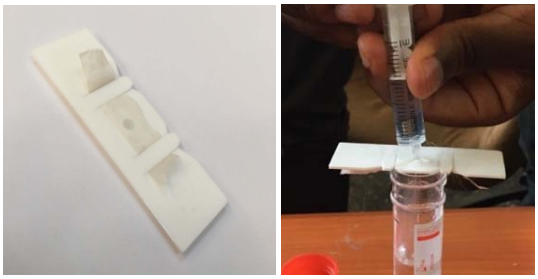

Fig. 5. 1st iteration filter and its holder (left) and in use with a syringe (right)

A strong recommendation from the field was that standardized filters and diagnostic instruments widely used in the lab in Nigeria should be optimized, simplified and used as a design reference.

3) Local production.

The possibility of local manufacturing was well validated as locals were not enthusiastic about importation of diagnostic products from Asia. Their usual experience when their imported medical product breaks down was saddening.

4) Even though the sample holder and the illumination module were designed to be 3D-printed, the capacity of 3D-printing in the field is not advanced enough to produce our models with the desired quality. Based on this input, alternative types of materials and distributed manufacturing techniques should be considered to ensure smooth local production.

C. Second iteration

Our first prototype was optimized based on the insights from the first field research. A prototype of the improved output of the second design iteration Schistoscope 2.0 was developed as shown in Fig. 6.

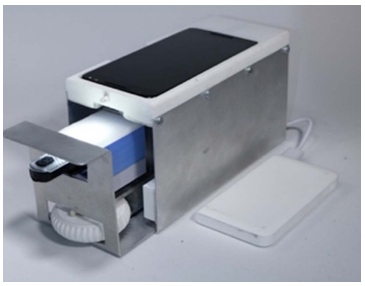

Fig. 6. 2nd Design iteration outcome with smartphone

1) Optimization of technical optics

The new system design now has a more rigid metallic frame which is robust against vibration, and misalignment of the optical components. Translating the Z-axis to ensure optimal image quality was attained by adjusting the focus knob which translates the sample plane with improved precision.

A smartphone model manufactured in Nigeria was used in this design iteration. Unfortunately, the resolution of the phone camera and display were not sufficiently high enough for our desired goal. The AI algorithm was further developed to enable testing with the samples from the field.

2) Integrated sample preparation

The membrane filter commonly used in Nigeria was used to test the second prototype to ensure compliance with the WHO standard.

The filter holder was separated from the main embodiment to prevent cross-contamination of urine. The new filter holder (See Fig. 7) is placed in the drawer which is mounted on the body without contacting other parts. For the sample preparation, the currently used syringe and urine cup were utilized to optimize the procedure.

Fig. 7. 2nd iterated design 3D-printed filter holder placed on urine cup

3) Local production.

The material for the main body was sheet metal which is stronger and more durable. The metal bending is not too complex production technique and repeatable at the local workshops. This will make the device easier to repair and maintain. The sample holder and the knob which control the focus requires higher precision, hence, they were 3D-printed with ABS (Acrylonitrile Butadiene Styrene).

D. Field Research II

The key objective of the second field research was to demonstrate Schistoscope 2.0, confirm the improvements based on the input from the first iteration, and look for further opportunities for improvement. The Schistoscope 2.0 was tested with real samples at the University of Lagos. Furthermore, field visits were made to peri-urban settings for simulating the diagnostic test in practice. In parallel, discussions and co-creation sessions continued with relevant stakeholders (See Fig. 8).

Fig. 8. Discussion with health experts (Left) and demonstration at the peri-urban setting (Right).

All these planned activities, helped the design team to gain a deeper understanding of the potential problems of the context and the potential value of the Schistoscope. An impression of the interviews with the stakeholders can be accessed here: https://www.youtube.com/watch?v=gG0hsmXbKq4.

Some problems identified during the first field trip were found to be resolved. Still, there were recurring issues such as the material and structure of the metallic frame. The design of the filter and its holder still requires lots of attention also. Meanwhile, new challenges emerged:

1) Optimization of technical optics

Even though the overall stability was improved, the metallic frame was *still not precise enough* to support vertical alignment. Shape and size of the used smartphone reduced the degrees of freedom in the design of the desired emobiment. The relatively high cost and reduced capacity of the backup battery were of major concerns.

Other issues relating to the maintenance and servicing of the device includes the fragility and difficulty to replace the phone screen and used lens. Therefore the need to engage with local phone repair shops is critical.

The functionality of the developed AI algorithm (See Fig. 9) was well valued by local experts. The processing speed which allowed egg detection and estimation in barely 4 seconds, was considered highly sufficient. More feedback was required for users to prevent any human error. As the phone has a GPS sensor incorporated, the data collection and mapping seem realizable with much less effort.

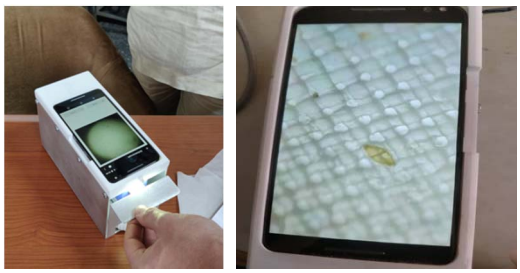

Fig. 9. Pictures of filtered S. haematobium eggs captured with Schistoscope 2.0

2) Integrated sample preparation

There were multiple drawbacks identified with the sample holder (see Fig. 10). First, the syringe was not well secured in the holder which *causes spillage of the urine samples*. Due to the small pore sizes and amount of volume injected through them, *the pressure on the mesh is high* and since the sample holder *does not have a handle,* easy spillage of content is observed. An interesting outcome from the frame design is that the drawer for the sample holder (see Fig. 6) *worked smoothly in terms of usability on the field*.

Fig. 10. The difficulty of using the customized holder (Left) and the standard filter and filter holder (right)

3) Local production.

The main material, sheet metal, was found as too expensive for local production. It should not be neglected that the sheet metal corrodes easily in such humid weather. To allow more precise and durable manufacturing and maintenance, 3D-printing was considered to be a more promising option. However, the limitations that were found in the previous iteration should be overcome to realize this.

IV. DISCUSSION

During the iterative design process, we were able to validate our assumption on the field and adapt our design to match with the local healthcare context and need of the end-users. For the remaining challenges, we determined the key problems to focus on to further improve the Schistoscope. The key insights and the current directions we are exploring are summarized in Fig. 14. The third iteration is in progress from February to July 2019 *to* optimize the main challenges as *below*. Afterward, we will continue with the validation and iteration of the results in a lab setting and *t*he field with the stakeholders.

1) Optimization of technical optics with Rasberry Pi

Although a smartphone has the advantage that it is locally repairable, it also severely limits the possibilities of the technical design. We concluded that there is a need for a customized imaging system for optimal effectivity of the algorithm. Therefore, the use of a Raspberry Pi or similar development board was suggested. Working with the development boards directly is more efficient in terms of coding rather than running on an android system. Adopting Raspberry Pi will enable the modular design and make it more efficient in terms of physical embodiment, battery capacity, and illumination. Adapting to a new component or expanding the functionality would be relatively easier. Nevertheless, working with a smartphone still has many benefits such as its ease of use, availability and familiar interface. The current prototype is being developed as in Fig. 11.

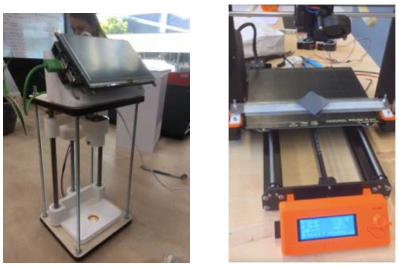

Fig. 11. 3rd design iteration with Raspberri pi and development of dedicated 3D Printer.

2) Integrated sample preparation: exploring both centrifuge and filtration methods.

For the urine filtration method, the holder has to be re-designed to prevent the spillage and solve usability issues in the next iteration (See Fig 12). The locally produced customized filter will have a high potential value in terms of sustainable supply and efficiency of Field of view. Moreover, the filter size relates to the required number of field of view (FoV) which influences the design of the technical optics. The cost and benefits of the two options will be considered more thoroughly in the next iteration.

Fig. 12. Outcome of the third iteration: filter holder design

Staining: As mentioned, the staining will increase the contrast of the target eggs against the background. This will increase the sensitivity of the algorithm. However, the supply of the staining chemicals and the accompanying training should be considered in this case especially in the remote settings.

Based on input from the field, we decided to develop a Frugal Centrifuge (see Fig. 13), which optimizes the centrifuge specifically for the detection of eggs in urine. It is our goal to ensure that the product is low-cost, locally manufacturable, and easy-to-use.

Fig. 13. Low-cost, locally manufacturable and maintainable centrifuge

3) Local production with optimized 3D-printer

Many local experts suggested the use of plastic for the embodiment design considering the context. To enable more detailed and easy-to-clean embodiment, 3D-printing seems to be the most promising option for manufacturing for the first batch of Schistoscopes. As the local capacity of 3D-printing is not ready, we aim at setting up a local manufacturing unit with several optimized 3D-printers (see Fig. 11) with independent power supply systems. We hope that our current 3D-printer modification will overcome the current limitations on the field.

V. CONCLUSION

We conceptualized the novel ideas for digital microscopy by iterative design process of Schistoscope in three different design iterations. To fill the diagnostic gap of Schistosomiasis in Nigeria, we believe that our method to explore with the potential stakeholders outside the lab-setting provided useful insights for the optimization of our technical system design during the design process.

Engaging local stakeholders from the early stage of the R&D process has improved our design methods to meet local healthcare needs. In the next stage of this research, we will further develop the three focus areas, and validate again with the potential stakeholders. We plan to repeat this cycle until a practical product that can be validated with a large sample size is realized targeting February 2020. After the validation in the lab, we will start testing with communities based on standard ethical approval. We believe that this design thinking and process will benefit researchers focused on using science and technology for societal benefit.

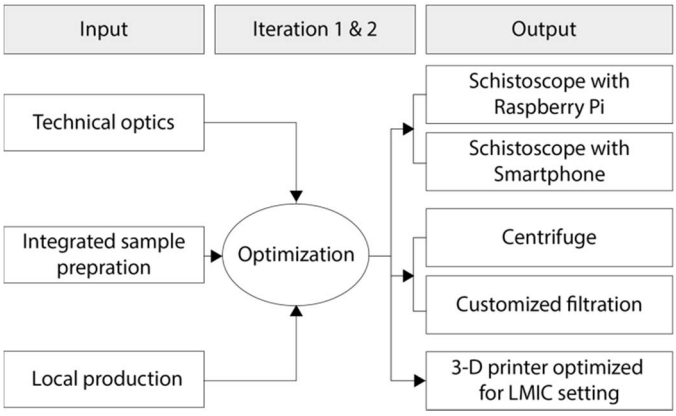

Fig. 14. An iterative process that has led to the current work-in-progress

ACKNOWLEDGEMENT

We want to acknowledge design team Zoom; Antonio Chozas, Joy Hooft Graafland, Satyajith Jujjavarapu, Salvador Lluch, Jasper Faber and Sonali Patel for their tremendous efforts in the design lab as well as in the field. We thank Opeyemi Oladunni, the University of Ibadan, Dr. Oluwatoyin P.Popoola, the University of Lagos for sharing their knowledge and expertise. We would also like to thank Ir. Henk Kuipers for providing support and insights. And Last but not we highly appreciate the continuous support Dr. Lisette van Lieshout of LUMC. The project has been carried out under the umbrella of the Diagnostics for All Program (www.tudelft.nl/diagnostics-for-all) of Delft Global Initiative.

REFERENCES

[1] Holmström, O., et al., *Point-of-care mobile digital microscopy and deep learning for the detection of soil-transmitted helminths and Schistosoma haematobium.* Global health action, 2017. **10**(sup3): p. 1337325-1337325.

[2] Tchuem Tchuenté, L.-A., et al., *Moving from control to elimination of schistosomiasis in sub-Saharan Africa: time to change and adapt strategies.* Infectious Diseases of Poverty, 2017. **6**(1): p. 42.

[3] Koydemir, H.C., et al., *Design and validation of a wide-field mobile phone microscope for the diagnosis of schistosomiasis.* Travel Medicine and Infectious Disease, 2018.

[4] Gryseels, B., et al., *Human schistosomiasis.* The Lancet, 2006. **368**(9541): p. 1106-1118.

[5] Gray, D.J., et al., *Diagnosis and management of schistosomiasis.* BMJ, 2011. **342**: p. d2651.

[6] Rajchgot, J., et al., *Mobile-phone and handheld microscopy for neglected tropical diseases.* PLoS neglected tropical diseases, 2017. **11**(7): p. e0005550-e0005550.

[7] Bogoch, I.I., et al., *Evaluation of portable microscopic devices for the diagnosis of Schistosoma and soil-transmitted helminth infection.* Parasitology, 2014. **141**(14): p. 1811-1818.

[8] Utzinger, J., et al., *New diagnostic tools in schistosomiasis.* Clin Microbiol Infect, 2015. **21**(6): p. 529-42.

[9] Ajibola, O., et al., *Tools for Detection of Schistosomiasis in Resource Limited Settings.* Medical Sciences, 2018. **6**(2): p. 39.

[10] French, M.D., et al., *Schistosomiasis in Africa: Improving strategies for long-term and sustainable morbidity control.* PLOS Neglected Tropical Diseases, 2018. **12**(6): p. e0006484.

[11] Agbana, T.E., et al., *Imaging & identification of malaria parasites using cellphone microscope with a ball lens.* PloS one, 2018. **13**(10): p. e0205020-e0205020.

[12] Balsam, J., et al., *Low-cost technologies for medical diagnostics in low-resource settings.* Expert Opinion on Medical Diagnostics, 2013. **7**(3): p. 243-255.

[13] Switz, N.A., M.V. D'Ambrosio, and D.A. Fletcher, *Low-Cost Mobile Phone Microscopy with a Reversed Mobile Phone Camera Lens.* PLOS ONE, 2014. **9**(5): p. e95330.

[14] Ephraim, R.K.D., et al., *Ultra-low-cost urine filtration for Schistosoma haematobium diagnosis: a proof-of-concept study.* The American journal of tropical medicine and hygiene, 2014. **91**(3): p. 544-546.

[15] Dawaki, S., et al., *Prevalence and risk factorsof Schistosomiasis among Hausa communities in Kano State, Nigeria.* Revista do Instituto de Medicina Tropical de Sao Paulo, 2016. **58**: p. 54-54.

[16] Hotez, P.J., *Blue Marble Health: An innovative Plan to Fight Dieseases of the Poor amid Wealth*. 2016, Baltimore: John Hopkins University Press.

[17] Engel, N., et al., *Addressing the challenges of diagnostics demand and supply: insights from an online global health discussion platform.* BMJ Global Health, 2016. **1**(4).

[18] Boeijen, A., J. Daalhuizen, and J. Zijlstra, *Delft Design Guide: design strategies and methods*. 2014, BIS Publishers.

[19] Clara Beatriz Aranda, J., J. Santosh, and M. James, *Towards A Framework for Holistic Contextual Design for Low-Resource Settings.* International Journal of Design; Vol 10, No 3 (2016), 2016.