Schistoscope
Smartphone versus Raspberry Pi based low-cost diagnostic device for urinary Schistosomiasis

Carel Diehl, Jan; Oyibo, Prosper; Agbana, Temitope; Jujjavarapu, Satyajith; Van, G. Young; Vdovin, Gleb; Oyibo, Wellington

DOI
10.1109/GHTC46280.2020.9342871

Publication date
2020

Document Version
Final published version

Published in
2020 IEEE Global Humanitarian Technology Conference, GHTC 2020

Citation (APA)
Carel Diehl, J., Oyibo, P., Agbana, T., Jujjavarapu, S., Van, G. Y., Vdovin, G., & Oyibo, W. (2020). Schistoscope: Smartphone versus Raspberry Pi based low-cost diagnostic device for urinary Schistosomiasis. In *2020 IEEE Global Humanitarian Technology Conference, GHTC 2020* Article 9342871 IEEE. https://doi.org/10.1109/GHTC46280.2020.9342871

Schistoscope: Smartphone versus Raspberry Pi based low-cost diagnostic device for urinary Schistosomiasis

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

Prosper Oyibo
Mechanical Engineering
Delft University of Technology
Delft, The Netherlands
P.O.Oyibo@tudelft.nl

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

Satyajith Jujjavarapu
Industrial Design Engineering
Delft University of Technology
Delft, The Netherlands
saatyyya@gmail.com

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

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

Wellington Oyibo
ANDI Centre of Excellence for Malaria Diagnosis,
University of Lagos
Lagos, Nigeria
woyibo@unilag.edu.ng

2020 IEEE Global Humanitarian Technology Conference (GHTC) | 978-1-7281-7388-7/20/$31.00 ©2020 IEEE | DOI: 10.1109/GHTC46280.2020.9342871

***Abstract*--Schistosomiasis is a neglected tropical disease of Public Health importance affecting over 252 million people worldwide with Nigeria having a very high number of cases. It is caused by blood flukes of the genus *Schistosoma* and transmitted by freshwater snails. To achieve the current global elimination objectives, low-cost and easy-to-use diagnostic tools are critically needed. Recent innovations in optical and computer technologies have made handheld digital and smartphone-based microscopes a viable diagnostic approach. Development, validation and deployment of these diagnostic devices for field use, however, require the optimisation of its optical train for the registration of high-resolution images and the realisation of a robust system design that can be locally produced in low-income countries. Field research conducted in Nigeria with active involvement of key stakeholders in research and development (R&D) led to the design of an initial prototype device for the diagnosis of urinary schistosomiasis, called Schistoscope 1.0. In this paper, we present further development of the Schistoscope 1.0 along two parallel design trajectories: a Raspberry Pi and a Smartphone-based Schistoscope. Specifically, we focused on the optimization of the optics, embodiment design and the electronics systems of the devices so as to produce a robust design with potential for local production.**

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

I. INTRODUCTION

A. *Schistosomiasis*

Schistosomiasis is endemic in 76 countries and territories around the world [1] with an estimated 779 million people at risk of infection, and approximately 252 million people are currently infected [2]. It presents substantial public health and economic burden as it is a disease of poverty. Schistosomiasis is caused by blood flukes of the genus *Schistosoma,* and it is transmitted by vectors (freshwater snails) living in streams from where the parasites are contracted when humans come in contact with water while carrying-out their daily activities such as washing, bathing, and kids playing or swimming and wading through to the next community due to absence of bridges.

Both *intestinal schistosomiasis (S. mansoni)* and *urinary schistosomiasis (S. haematobium)* are endemic in Africa [3-6] with Nigeria having the highest burden of the disease. Current global to national strategies are aimed at eliminating this preventable disease by employing interventional measures that include the use of mass drug administration (MDA) with approved medicines alongside vector control and hygiene programmes. In the drive for attaining elimination targets, diagnosis for adequate monitoring of interventions and surveillance is critical. Microscopy examination of urine samples, prepared by filtration, sedimentation or centrifugation, is currently the WHO reference standard for the diagnosis of *urinary schistosomiasis* [7]. However, the laborious nature, time-consuming, high cost, the bulkiness of equipment, shortage of required expertise and lack of required maintenance skills, replaceable parts and associated human errors/subjectivity has limited its availability in remote rural communities [7, 8]. Hence, a field adaptable, rapid and easy-to-use diagnosis is critical for the prompt detection of cases, mapping communities and monitoring trends or progress of interventions toward the attainment of the elimination targets. This paper reports on the accomplishments of the first phase of our INSPIRED (INclusive diagnoStics for Poverty RElated parasitic Diseases) project which brings together a multidisciplinary team composed of biomedical scientists, engineers, public health specialists and product designers from universities in The Netherlands, Nigeria and Gabon. Here, we discussed and compared results from two parallel design trajectories, based on the Raspberry Pi and Smartphone, for an automated diagnostic device for urinary schistosomiasis.

B. Technological Developments, Challenges and Opportunities

Rapid progress in optical and computer technologies has made smartphone- and Raspberry Pi-based microscopes promising alternatives for field diagnosis of schistosomiasis [9]. Their availability and portability make them suitable for use outside of a typical lab setting [7, 10, 11]. Also, with integrated data-driven algorithms for automated detection and quantification of *S. haematobium* eggs in filtered urine samples, the lack of experienced microscope operators at the point-of-care and the challenge of data storage can be compensated for. Based on the performance of the algorithm, diagnosis can be achieved with sufficient performance and operational utility. Aside from automated sample analysis, detection, and infection load estimation, the imaging platform could also enable seamless data sharing for disease mapping toward effective control and elimination. This provides an additional utility over conventional manual microscopy where data will be manually generated, recorded and archived.

Despite a wealth of technological innovation in this field which meets many technical and medical criteria, there are still challenges in implementing handheld-microscopy devices in resource-constrained environments [12]. Smartphone-based microscope provides relatively poor image quality due to the inherent aberration of the optics and the limitation posed by the numerical aperture [13]. Furthermore, the limited field of view (FoV), results in the need for multiple measurements of the sample, which reduces the performance of the diagnostic device [14]. An optical setup which consists of a smartphone optical train aligned with a smartphone micro-objective lens (positioned in a reverse format as shown in Fig.1) has shown promising results. This optical configuration provides a relatively larger FoV (the entire sensor plane), and a resolution limited mostly by the pixel size of the camera sensor [15].

Due to an enormous logistics effort required, Currently available diagnostic devices produced in the West are expensive, scarce, and difficult to maintain (due to lack of spare parts and required technical skills) at the point of need in sub-Saharan Africa [13]. Mass production of components for the consumer electronics market in recent years, enabled the fabrication of low-cost, effective and portable digital imaging devices [7]. Manufacturing these devices by using locally sourced materials could also reduce costs as well as improve maintenance due to the availability of spare parts in the target areas. Integrating this with innovative manufacturing pathways (i.e. local distributed production) [12], we could overcome import dependency and unnecessary long distribution value chains, that comes with additional costs. Accessible manufacturing technologies like 3D-printing and Laser-cutting offer new opportunities of setting up local production facilities that can produce and supply the devices and spares for local use [13].

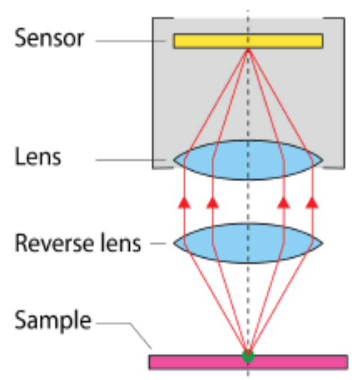

Fig. 1. Reverse lens setup

Once these challenges are addressed, portable digital microscopy could provide and create access to high-quality schistosomiasis diagnostics. Consequently, timely information on the distribution of the disease, which will reinforce the control and elimination efforts could also be made readily available for use by interested organisations and the National Programme [13]. The design goals and challenges for the Schistoscope development are discussed in the next section.

II. DESIGN SETUP

A. *Gaps, Challenges and opportunities for Schistoscope 1.0 Improvement*

A prototype of a diagnostic device for urinary schistosomiasis called the Schistoscope 1.0 was developed in [13] through an iterative design process with implementation research conducted in Nigeria and involving key stakeholders in the research and development process (see Fig. 2). After several design iterations, the main body of the Schistoscope 1.0 was fabricated in a local workshop. This makes the device easier to repair and maintain locally. The authors further reported on the design of a simple 3-D printed sample holder used with widely available filter material for urine filtration. The device was tested with real urine samples at the University of Lagos and at peri-urban settings in Lagos Nigeria for simulating the diagnostic test in practice.

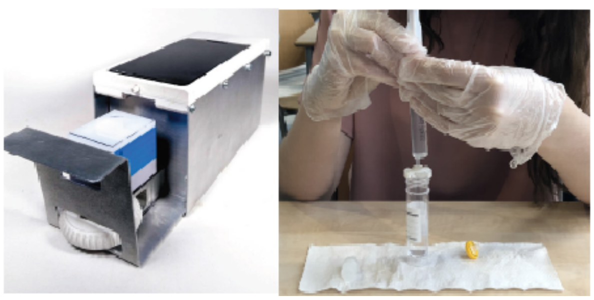

Fig. 2. Schistoscope 1.0 (left) and filter process (right)

From the implementation and development research, a range of practical design issues, which needed further consideration in the next design iteration, were identified and hereby proposed. The recommendations listed below, therefore, formed the basis of the next design iteration contained in this paper.

1) Local manufacturing: The use of plastic as an alternative to sheet metal 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 the Schistoscopes as Makerspaces and small businesses which provide 3D printing services and resources are available in Nigeria and other Low and Middle-Income Countries.

2) Mobile phone: A smartphone has the advantage of being locally repairable. However, this severely limits the possibilities of the technical design. The use of a Raspberry Pi or a similar computer could be an interesting alternative in terms of the ease of implementation of the control and artificial intelligence algorithms because it has a large open-source community. Adopting a Raspberry Pi will also enable the modular design and make it more efficient in terms of physical embodiment and battery capacity. Adapting to a new component or expanding the functionality would be relatively easier. Nevertheless, using a smartphone still has many benefits such as its ease of use, availability and familiar interface.

3) Urine filtration: The syringe was not well secured in the holder, which *caused spillage of the urine samples*. Due to the small surface area of the cloth filter and amount of volume injected through it, *the pressure on the mesh was high,* and since the sample holder *does not have a handle*, easy spillage of content was observed. The recommendation was to use either established WHO protocol, or at least to use standard filters.

Based on this feedback from the field, the design process for the next design iteration was initiated. The project was carried out between February and July 2019.

B. *Design Goals for Schistoscope 1.0 improvement*

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 sub-Saharan Africa (with the use of* ***locally available components and 3D-printing****).*

For the specific development goals, product scope is defined, which relates to the primary function of the product, namely diagnosis of urinary schistosomiasis, and its sub-functions and components. The three main component groups are the embodiment of the product, the optics, and electronics. These three components overlap, interact with each other and are responsible for the successful execution of the diagnosis of schistosomiasis. Hence, we initiated two parallel Schistoscope designs trajectories, one based on the Raspberry Pi (Schistoscope RP) and the other based on the smartphone (Schistoscope SP). Also, the Schistoscope has to be culturally accepted and trusted, while keeping costs low.

The four main drivers were chosen to guide the development focus are as follows:

1) Robustness: The product needs to withstand the harsh tropical environment in Nigerian, such as humidity and heat. Also, to aid reparability, the product should be built with locally accessible parts in the years following the deployment of the device.

2) Potential for Local Production: The product should be locally producible, using largely standard off-the-shelf components in combination with local available distributed production methods.

3) Intuitiveness: In order for the product to be accepted and used, operational considerations such as the ease-of-use should be given priority with supporting use cues. Furthermore, the choice of materials and the appearance should contribute to better product appreciation and acceptance.

4) Hygiene: Aseptic considerations in the handling of the device, since it works with urine, are imperative to ensure that the product could be easily cleaned to prevent possible cross-contamination.

C. Technical Design Challenges for Schistoscope RP & SP

The three main technical design challenges of the technology behind the product are:

1) Accurate alignment of the camera sensor, micro-objective lens and sample in order to reduce aberrations in the optical system.

2) Imaging the filtered sample in a single FoV, with optimal illumination and sufficient resolution for automated analysis.

3) Robust design and material selection of the casing taking into consideration 3D-printing and off-the-shelf components, in order to be resistant against the environment in rural Nigeria.

III. DESIGN RESULTS

A. Schistoscope RP

The Schistoscope RP (see Fig. 3) analyses schistosoma eggs by means of an algorithm running on a Raspberry Pi. The device was designed such that its casing and development board are modular. This will enable easy and quick part replacement in case of device failure at the point of need.

1) Optics: The Schistoscope RP made use of a Raspberry Pi Camera Module V2.1, which has a relatively large sensor size (3.674 × 2.760 mm) and offers extensive control over its settings. In order to image the entire standard 13 mm (urine) filter, an inverted microscope objective lens (4×) was placed at a distance of 16 cm between the sample and the lens, and 3.5 cm between the lens and camera as shown in Fig. 3. A microscope condenser lens was used to focus the light in such a way that all the light that passes through the sample continues through the objective lens. Achieving this illumination will result in the maximum contrast. Additionally, providing an illumination source with high intensity positioned beneath the sample will reduce the effect of stray light, which can result in image noise. A manual focusing mechanism consisting of a 3D printed rotating knob with a thread pitch of 3 mm and 3 revolutions was developed to accurately adjust the camera to the appropriate focal plane to mitigate the effect of the defocus aberration in the registered image.

2) Electronics: The internal electronic design of the Schistoscope RP consists of a variety of electronic components which include a Raspberry Pi 3B+ which use Python scripting for implementing all the software functionality. The Raspberry Pi 3B+ is used in combination with a HAT (Hardware on top) which makes it easier to place, on a smaller footprint, electronic components like the power management block, I2C breakout, Buzzer, EEPROM, screen connector, indicator light, LED controller, fan controller and a button connector. These design choices result in a modular system with components that are easy to repair and upgrade. However, one disadvantage is that the components may be less protected from dust and other contextual factors like humidity.

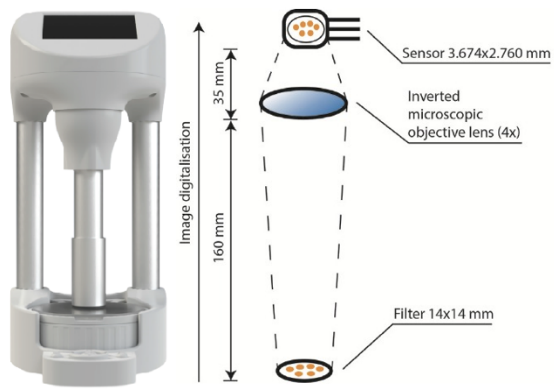

Fig. 3. Schistoscope RP (left) with working principle of sensor and lens combination (right)

3) Embodiment: All parts of the Schistoscope RP casing were designed based on three main drivers: robustness, hygiene and the potential for local production. They consist of the upper cover (contains the display and closes the upper frame), upper frame (contains the lens holder, camera sensor, Raspberry Pi), structural beams (gives structure to the device and helps position the optics at appropriate distance from the sample), base (contains the

LED, fan, input buttons, USB protocol) and base plate (closes the base). The design of the casing was optimized for mechanical strength and robustness in terms of stiffness, material use and printability by performing static Solidworks load simulations, using Finite Element Method (FEM). This minimises deflection of the structural connection between the lens/ sensor and the sample stage which can result in a noticeable shift in the field of view.

User inputs are with the help of five buttons which are a ‘power’ button, an ‘OK’ button, a ‘back’ button and two ‘directional’ buttons used for navigating menus and zooming the sample images. The Schistoscope RP’s feedback to the user includes the diagnosis of the patient, the amount of eggs found in the sample by the algorithm and whether the sample is in focus or not, are provided via a 3.5 inch thin-film transistor (TFT) display with a resolution of 320 × 480 pixels.

4) Production and maintenance: Most components of the Schistoscope RP such as the electronic components, fasteners and structural aluminium pipes are available off-the-shelf and can be easily ordered from China via Aliexpress or similar online stores. The parts that are custom designed include the casing of the Schistoscope - which is 3D printed - and the printed circuit board. The cost of manufacturing one Schistoscope RP is estimated at 125 Euro excluding VAT, shipping cost of off-the-shelf components.

Certain parts of the Schistoscope RP, such as the glass staging area, need to be cleaned after every sample analysis or every day to remove any cross-contamination by infected urine. Other parts need to be cleaned after a certain period of time to remove any dust or mold that has found its way into the device. It might also be necessary to perform corrective maintenance in cases of device overheating or the failure of electronic components. Software updates to add new features and performance improvements of the device can be automatically installed when the device is powered on and connected to the internet via a WiFi network.

B. Schistoscope SP

The Schistoscope SP (See Fig. 4) is a smartphone-based design that was developed with the main goal of creating a high-resolution image of the sample. A combination of the optics, focusing system and the sample arm is necessary for realizing the desired high resolution image.

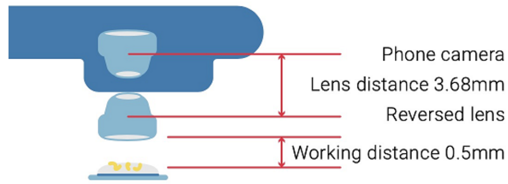

Fig. 4. Schistoscope SP (up) with working principle of sensor and lens combination (down)

1) Optics: The Schistoscope SP optics system consists of a smartphone camera and a reversed lens mounted between the phone lens and the internal framework as shown in Fig. 4. The light sources and a frosted clear acrylic diffuser, positioned 10 mm above the source form the illumination system. This combination allows even distribution of light across the specimen. The resolution of the optical system depends on the numerical aperture of the micro-objective lenses. Higher numerical aperture equals higher resolution. Also, the FoV strongly influenced the design of the sample preparation. The complementary metal-oxide-semiconductor (CMOS) sensor size is 4.8 x 6.4 mm but creates an effective image of 4 x 6 mm as a result of the image edge being blurred because of a reduction in the lens’ resolution around its edge. Hence the sample membrane is designed to be smaller than the effective FoV.

The smartphone camera has a glass layer over it for protection, thus creating a distance of 3.68 mm between it and the reverse lens. This distance reduces the possible distance between the reverse lens and the sample to 0.5 mm which restricts the range of movement and steps of the focus mechanism, and also the placement of samples. The focus mechanism performs the high precision task of moving the sample slide along the axis of the reversed lens. It consists of 3 main parts: a knob, a thread and a movement part. The thread is the leading component of this system as it enables movement of the sample in the vertical direction. The knob houses the female part of the thread. The movement part moves it over a distance of 2 mm. It is hollow, so it houses the light and holds the diffuser on top. The sample holder, which is a U-shaped track, functions as an insertion system and holds the sample slide in position from where it is moved by the focus mechanism.

2) *Electronics:* After patient diagnosis, relevant diagnostic data are uploaded to a cloud database via the smartphone using 4G network. This data can influence the future treatment and prevention of the disease. Other electronics of the Schistoscope SP include a circuit, control for the smartphone, sample illumination LED and a 20,000 mAh Xiaomi power bank which can power the smartphone and the LED for three days in rural areas without electricity supply.

3) Embodiment: The internal framework of the Schistoscope SP consists of a uniform top part with a hollow axis which aligns all holes, from the lens of the phone to the movement part in the knob, and the bottom part which secures the knob. A phone holder in the top part of the framework fixates the phone together with its charging cable and earphone jack. A cone shape underneath the phone holder which ends in a cylinder is designed to guide the movement parts. The clamping of the knob is done by fixating the second internal framework part to the first, using bolts in nuts.

The Schistoscope SP has three buttons: the power, light and home screen buttons. The power and the light buttons are connected with a wired switch to the power bank. The home screen button works as an extension of the original home screen button of the phone. The designed Schistoscope SP uses the screen of the phone as the main form of visual feedback to its user.

4) Production and maintenance: Almost all the manufactured parts of the Schistoscope SP (internal framework, movement part, buttons) are 3D printed. The male and female thread and the sample holder were produced on a lathe machine from stainless steel because they need to withstand high forces and wear. Polyester Velcro, which is suitable in context of moisture and light, is used to secure the power bank to the housing. The cost per device without the cost of the sample slide and the sample preparation device is estimated at 480 euro. The initial tooling and service costs for running the tools not taken into account.

There are three levels of the product system that are likely to be contaminated, which should be sanitized and disinfected regularly. These include the outer surface of the device, the sample holder and the filtration system which consists of a membrane, sample slide, snap ring, sample preparation device and syringes. The Schistoscope SP is designed for easy repair which can be done alone by one craftsman, using only standard screwdrivers, in a limited amount of time. The products' three levels of reparability (Level 1: opening the house, Level 2: removing the framework, Level 3: Disassembling the focus mechanism) make its maintenance time- and cost-efficient.

5) Sample Preparation Device: The sample preparation device (see Fig. 5) design focuses on hygienic usage and being leak proof, fulfilling the optics requirements of a relatively small 3.5 mm FoV compared to the Schistoscope RP with a 15 mm FoV. In addition, it keeps the membrane surface flat and improves handling while also reducing human error for the healthcare worker. It consists of three main components: The sample slide which is reusable after cleaning according to WHO guidelines and allows for easy insertion into the Schistoscope. A spout on top indicates where to put the syringe and for support when filtering the urine. The urine exits the sample preparation device through a hole at the bottom. It has a soft silicone rubber channel that helps press the membrane to the side of the sample preparation device. This creates a leak proof design which ensures the urine and eggs are contained in the 3.5 mm channel during the filtration process. It also aids in lifting the membrane as close to the optics system as possible to fulfil the 0.5 mm focal length requirement. The snap fit ring helps to hold the filter membrane tightly to the sample slide making it as flat as possible so as to reduce warping of the image. A rubber part is added to the top of the sample slide to prevent spillage during filtering.

Fig. 5: Sample preparation device

IV. DISCUSSION

In both the Schistoscope designs, all three product sub-systems; embodiment, optics and electronics were thoroughly developed (as described in section III), and the devices were built to implement the four main drivers: robustness, potential for local production, intuitiveness and hygiene. The performance of the two prototypes based on these drivers is summarized in Table 1.

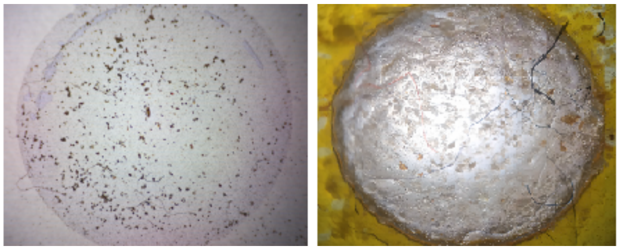

Fig. 6. Image of sample with eggs in one field of view obtained from Schistoscope RP (left) and Schistoscope SP (right)

The first objective of this project was to create a single FoV optics system with optimal illumination and sufficient resolution. The Schistoscope RP didn't fully satisfy this criterion, as a single field of view (15 mm) image was obtained in which *S. haematobium* eggs could be identified, but some of the terminal spines, which is the distinctive characteristic of these eggs were not visible. This issue can be resolved by using a high-end setup with an infinity corrected 4x objective and 200 mm tube and tube lens which would bring the cost of the device to above 500 Euros. A more affordable alternative is to increase the numerical aperture by using two Raspberry Pi Camera V2.1 lenses of which one is inverted. However, the image from the Schistoscope SP had a high enough quality to detect the spine of the *S. haematobium* egg (see Fig. 6). The second objective was the accurate alignment of the camera sensor, lens and sample in order for the product to function, which was met by both designs of the Schistoscope. However, there was clogging of the filter by urine sediment due to the small surface area of the filter used for the filtration process. This problem can be solved by using the standard filters with larger surface area but the designed optical system cannot image the entire standard filter in a one FoVs. Therefore, moving the sample along the X and Y axes to obtain multiple FoVs will be a preferred solution.

Finally, both products had a robust design made of materials that are resistant against the environment in rural Nigeria. The final design of the Schistoscopes consisted of materials that are 3D printed as well as purchased off-the-shelf. However, it took about 40 hours to 3D-print the various components of each device. Using a Laser-cut model would greatly reduce this delay. Also, the production cost per unit for the Schistoscope RP and the Schistoscope SP were Euro 125 and Euro 480 respectively. The Schistoscope SP is therefore thrice the price of the Schistoscope RP. Hence, the Schistoscope RP, if developed further will be a more suitable low-cost diagnostic device for urinary schistosomiasis.

TABLE I. PERFORMANCE OF SCHISTOSCOPE PROTOTYPES IN DESIGN MAIN DRIVERS

Main Drivers	**Schistoscope RP**	**Schistoscope SP**
Robustness	The embodiment consists of structural tubes which provides a stable design and protects the electronics components. Also, a fan with an air filter located in the product base plate, dissipates heat from the electrical components, resulting in a dust proof product.	The internal framework, housing and its ribs, enhance strength and stiffness. The sample holder was produced with steel to withstand wear and tear caused by abrasive cleaners. A large power capacity that can withstand 3 days diagnostic without recharging is implemented in the design.
Potential for Local Production	The parts are either locally produced by 3D printing or bought off the shelf. Hence the product can be easily manufactured at a cost of Euro 125 per unit and damaged parts can be reprinted or replaced locally.	Local manufacturing and off-the-shelf parts were used in the design and the cost per unit of the device is Euro 480. The product level assemble makes device maintenance cost and time efficient
Intuitiveness	The device is designed with multiple use cues such as: ● A specific circle at the bottom of the sample stage to aid correct placement on the focus knob ● A circle of light projected on the glass stage to which serves as cue on where to place the sample for correct alignment ● Icons on the buttons for user guidance.	The device has use cues that suggest the user holds the device with two hands in different ways to secure stability. Also, the two sliding buttons in the housing have a coloured bed indicating whether they are switched on or off and icons to indicate functionality. A slight blue colour ring is added around the rounded sample insertion hole to indicate the placement to the user.
Hygiene	Components which come in contact with the urine sample are easily removable and cleaned separately. Components are also designed to be rounded and smoothed for easy cleaning.	White is colour giving the product a hygienic feeling. Due to the design of the sample holder and the hole in the embodiment, samples can be inserted easily without touching any other parts.
Data	Enables data transfer to the cloud via WiFi technology.	Real time data can be uploaded to the cloud database via the smart phone through 4G network.

V. CONCLUSION

The goal of the project was 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 sub Saharan Africa (with the use of locally available components and 3D-printing). This was achieved by the further development of the Schistoscope 1.0 along two parallel design trajectories: a Raspberry Pi and a Smartphone-based Schistoscope. The three main component groups of the design were the embodiment, optics and electronics systems as prime focus. Both Schistoscopes were able to capture single FoV images of filtered schistosoma eggs (see Fig. 6), with optical alignment of camera, sensor and lens. Most of the materials used in the production were 3D printed while others were accessible off-the-shelf, hence easily replaced when damaged.

In our next design trajectory, the Raspberry pi design will be further developed because of its cheaper production cost. The standard filter with a larger surface area will be adopted along with a multiple FoVs optical system. To reduce the production, Laser-cutting would be explored for the embodiment design of the device. Also we will automate the process of imaging and analysing the prepared samples so validation with laboratory microscopy using a large sample size can be realized. After the validation in the lab, we will begin testing with communities in Nigeria based on standard ethical approval.

ACKNOWLEDGEMENT

We want to acknowledge the design teams. Schistoscope RP Team; Resy Aarts, Dione Leeger, Sam Kernan Freire, Bente Vermaat, Indy Vester, Jerry de Vos; and the Schistocope SP Team; Maite Gieskes, Tina Ekhtiar, Talitha Brenninkmeyer, Chenye Xu, Mingmei Yang, Jard Van Lent. We further want to thank Design coaches Stefan Persaud and Gerard Nijenhuis for their critical design thinking input This research has been partly funded by the NWO-WOTRO SDG programme grant INSPiRED (W7.30318.009).

.

REFERENCE

[1] Bruun, B. and J. Aagaard-Hansen, *The social context of schistosomiasis and its control: an introduction and annotated bibliography*. 2008: World Health Organization.

[2] Silva-Moraes, V., et al., *Diagnosis of Schistosoma mansoni infections: what are the choices in Brazilian low-endemic areas?* Memórias do Instituto Oswaldo Cruz, 2019. **114**.

[3] Gryseels, B., K. Polman, J. Clerinx, and L. Kestens, *Human schistosomiasis.* The Lancet, 2006. **368**(9541): p. 1106-1118.

[4] Steinmann, P., J. Keiser, R. Bos, M. Tanner, and J. Utzinger, *Schistosomiasis and water resources development: systematic review, meta-analysis, and estimates of people at risk.* The Lancet infectious diseases, 2006. **6**(7): p. 411-425.

[5] Utzinger, J., et al., *Schistosomiasis and neglected tropical diseases: towards integrated and sustainable control and a word of caution.* Parasitology, 2009. **136**(13): p. 1859-1874.

[6] van der Werf, M.J., et al., *Quantification of clinical morbidity associated with schistosome infection in sub-Saharan Africa.* Acta tropica, 2003. **86**(2-3): p. 125-139.

[7] 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.

[8] French, M.D., et al., *Schistosomiasis in Africa: Improving strategies for long-term and sustainable morbidity control.* PLoS neglected tropical diseases, 2018. **12**(6).

[9] Balsam, J., M. Ossandon, H.A. Bruck, I. Lubensky, and A. Rasooly, *Low-cost technologies for medical diagnostics in low-resource settings.* Expert opinion on medical diagnostics, 2013. **7**(3): p. 243-255.

[10] 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.

[11] Koydemir, H.C., J.T. Coulibaly, D. Tseng, I.I. Bogoch, and A. Ozcan, *Design and validation of a wide-field mobile phone microscope for the diagnosis of schistosomiasis.* Travel medicine and infectious disease, 2019. **30**: p. 128.

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

[13] Agbana, T., G.-Y. Van, O. Oladepo, G. Vdovin, W. Oyibo, and J.C. Diehl, *Schistoscope: Towards a locally producible smart diagnostic device for Schistosomiasis in Nigeria*, in *IEEE Global Humanitarian Technology Conference (GHTC).* 2019.

[14] 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.

[15] Jujjavarapu, S., *Automating the Diagnosis and Quantification of Urinary Schistosomiasis*, in *Electrical Engineering, Mathematics and Computer Science* 2020, Delft University of Technology.