Improving an optical diagnostics device for Schistosomiasis

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TU Delft

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Master thesis
Master Integrated Product Design
Faculty of Industrial Design Engineering

Graduation Committee
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Figure 1. Frontpage image: Two Schistoscpe 5 devices

Executive summary

Schistosomiasis is a Neglected Tropical Disease, prevailing mostly in poor and rural communities in sub-Saharan Africa, particularly those that heavily rely on water bound occupations, such as fishing and specific agriculture. In 2019, a total of 236.6 million people required treatment for schistosomiasis and only 1 million received it. Without treatment people are vulnerable for chronic infections and eventually death. Accurate diagnosis is crucial to reduce risks of chronic infections.

Schistosomiasis is currently diagnosed through the detection of parasite eggs in stool or urine specimens. Eggs are detected and counted by a trained microscopist examining the filter on a glass slide. This is difficult and hard work, requiring a non-ergonomic posture and medical training. Only a limited group of people can properly receive this training, due to a lack of resources for education. As an alternative the INSPIRED Project has developed the Schistoscope to automate this process to assist the microscopist.

The current prototype, the Schistoscope 4 is an automated digital microscope that analyses images through Artificial Intelligence to provide diagnosis. In 2021, the research group will execute a field study in Nigeria. The goal is to collect samples in highly infected communities and compare the work of the Schistoscope 5 to a standard microscopist. The Schistoscope 4 is considered insufficient for executing this field study.

Consequently, an improved device is required. An analysis on previous versions of the Schistoscope provided challenges for improvement. The challenges addressed in this graduation project are: (1) improve the stability and fixation of the camera. (2) Include the illumination in the optical set-up of the device and (3) allow for a change of view received by the camera. Furthermore, (4) the view of the camera must consistent and reliable. At last, (5) all systems must be integrated in to a stable embodiment, (6) protected from the outside environment. The graduation project uses a PDCA-cycle approach combined with systems engineering to structure the design process. With this iterative approach, the requirements are continuously evaluated and updated.

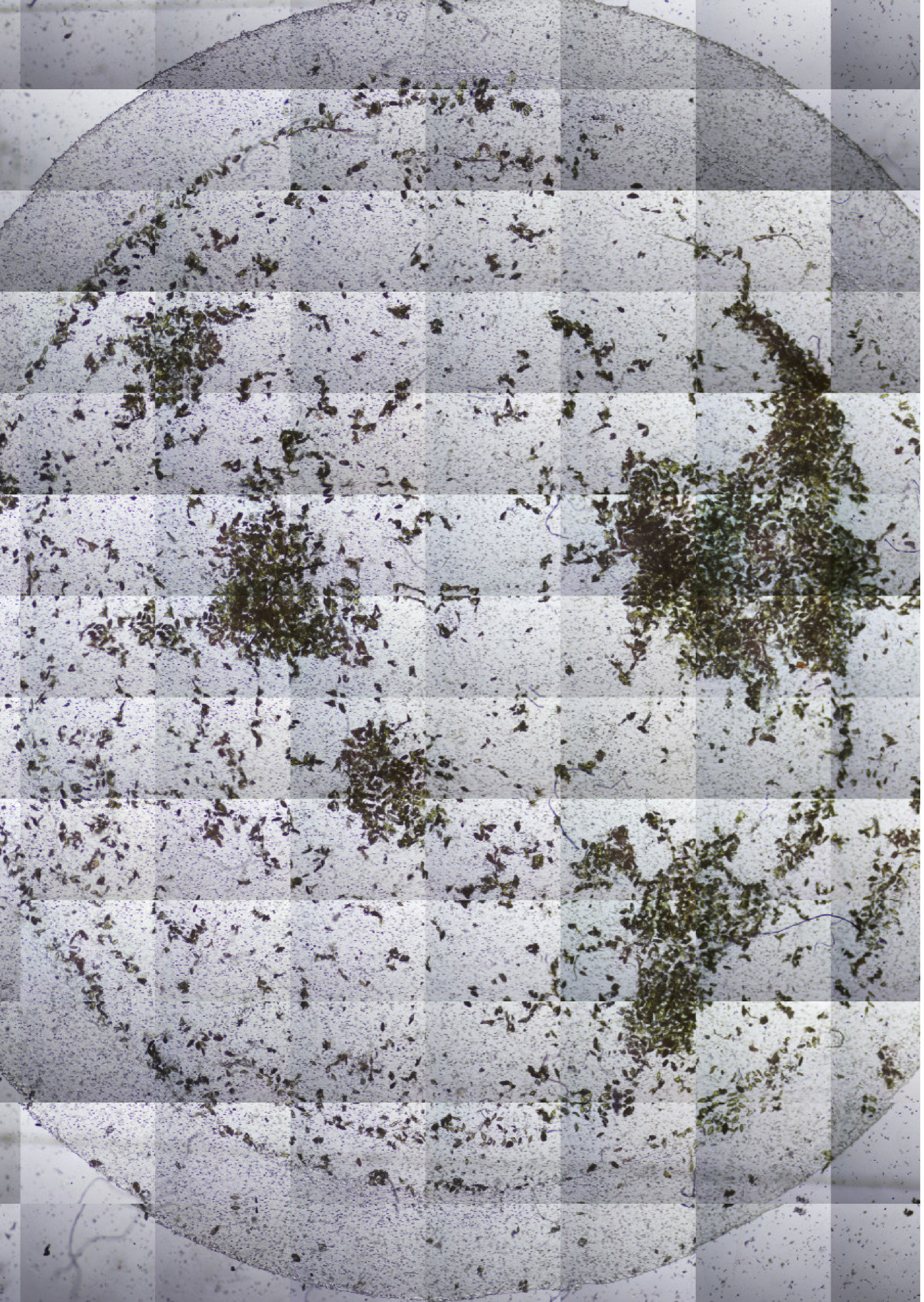
The final design presented in this thesis provides the research group with reliable and sufficient quality results. A stable construction with aluminium profiles allows for the required adaptability needed because of the dynamic nature of the research project. Additionally, the aluminium profiles provide easy attachment of numerous off-the-shelf components.

These off-the-shelf components provide consistent movement of the sample and optical system. They allow for changes in electronic hardware and overthrow the initial 3D-printed production method.

An enclosure system integrates all systems inside the device and protects these systems from impacts from the environment.

During the project, a total of three prototypes are produced, of which two devices are successfully transported to Nigeria, where they are operational in the field test laboratory. The Schistoscope 5 is a clear improvement of the previous prototypes and excels in stability of the components, reliability of movement and consistency in quality.

Content



1 Introduction

In this chapter, the relevant background information to understand the reason behind the project is explained. It shortly introduces the stakeholders and explores a basic understanding of Schistosomiasis and its impact worldwide.

Additionally, this chapter shows how this graduation project was structured and which design methods were used to create the final design and how the this is structured.

Figure 2: Scan result Schistoscope

Project and stakeholders

The aim of this graduation project is to provide the diagnostics device that supports the research project of INSPiRED. INSPiRED is a collaboration between:
- Leiden University Medical Center (LUMC),
- Delft University of Technology (TU Delft),
- University of Ibadan in Nigeria,
- University of Lagos in Nigeria
- CERMEL in Gabon.

The research project is aiming for development and validation of inclusive, smart, easy to use, cost effective and efficient optical devices for the diagnosis of poverty related parasitic diseases in Nigeria and Gabon. The project aims to reduce the burden of these diseases by conducting laboratory and field validation of its developed devices, and to engage stakeholders for the uptake of these devices in the healthcare systems [12].

In the INSPiRED team are PhD candidates Brice Meulah from LUMC and Prosper Oyibo from TU Delft. Their joined research aims create a reliable Artificial Intelligence (AI) algorithm for the detection of one off the poverty related parasitic diseases, called Schistosomiasis (see chapter Schistosomiasis). The research focusses on the detection of Schistosomiasis Haematobium eggs in urine-filtered slides that meets microscopy standards. They plan to execute a field research in Nigerian in 2021 to validate their developed AI/work.

The outcome of this graduation project will support the research projects work by providing a device that can capture reliable and accurate data, by building on previous research of the Schistoscope project. For several years, students and researchers have been developing automated diagnostics devices, focussed on detecting schistosomiasis eggs in urine. This project builds on their findings and previous prototypes by creating the next iteration of the Schistoscope [6].

Supervisory team

Besides the stakeholders connected to the INSPiRED research group, this graduation project is supervised by the following team.

Figure 3: J.C. Diehl

dr. ir. Jan Carel Diehl
Researcher connected to INSPiRED and acting as client on their behalf.

Chair of the supervisory team

Figure 4: J. Trappenburg

ir. Joep Trappenburg
Expert on design drawing, manufacturing, sustainability and development

Mentor in the supervisory team

Figure 5: Jo van Engelen

prof. dr. ir. Jo van Engelen
Expert on product development and marketing and integrated sustainable solutions

Mentor in the supervisory team

Experts included in INSPiRED

Figure 6

Dr. Temitope Agbana
Context expert

Figure 8

Ir. Satyaith Jujjavarapu
Software expert and developer of Schistoscope 4

Figure 7

ir. Prosper Oyibo
Artificial Intelligence expert

Figure 9

Msc. Meulah Brice
Medical expert

Schistosomiasis

One of the parasitic diseases INSPIRED focusses on is Schistosomiasis. Schistosomiasis is a Neglected Tropical Disease (NTD), prevailing mostly in poor and rural communities in sub-Saharan Africa. Since Schistosomiasis is a waterborne parasite, the disease affects particularly communities that rely heavily on water bound occupations, such as fishing and specific agriculture.

Infection

Schistosomiasis is a chronic parasitic disease caused by blood flukes that infiltrate human skin when in contact with contaminated water. The life cycle of schistosomiasis is part of a vicious cycle (figure 10). Parasite larvae, released by their intermediate host, a freshwater snail, penetrate human skin during contact with infested water. Once inside their new host, the larvae travel through blood vessels to intestines and bladder, where male and female larvae pair up and lay eggs. Some eggs are released into faeces or urine, into water. Due to insufficient hygiene facilities, the same water is used for their daily practices. The eggs hatch and release larvae, which search for a host, the circle is complete. Other eggs are trapped in body tissues, causing immune reactions and progressive damage to organs.

Mortality

Mortality due to Schistosomiasis is difficult to estimate, because of concealed pathologies such as liver and kidney failure, bladder cancer, and ectopic pregnancies. Scientific estimates vary between 24.000 and 200.000globally per year [4] [27][28].

Prevalence

Schistosomiasis prevails in countries with (sub) tropical conditions. The disease mostly affects poor and rural communities, particularly populations that heavily rely on occupations or domestic chores that take place in water, such as fishing, certain types of agriculture or cleaning.

Schistosomiasis is endemic in 78 countries. In 2019, a total of 236 million people required treatment yet only 1 million received it. Estimated is that 90% of the people requiring treatment live in Africa [25]. In Africa, Schistosomiasis is most prevalent in Nigeria, covering almost 11% of the worldwide distribution.

Schistosomiasis Haematobium

Of the five Schistosoma species, Schistosomiasis Haematobium is the most prevalent, in 54 countries worldwide, followed by Schistosomiasis mansoni in 52 countries [1]. Also, in Nigeria, the predominant species is Schistosoma Haematobium, 79.8% appearance in 31 states [9]. This thesis will focus on Schistosomiasis Haematobium, since it is the most prevalent species in Nigeria and around the world.

Treatment

Early treatment is key in reducing long term morbidity and preventing chronic infections. In endemic areas, praziquantel (preventive chemotherapy) treatment programmes are used periodically. These Mass Drug Administrations (MDA) are either aimed at school-aged children, adults considered to be at risk or entire communities. The frequency of MDA's is determined by the prevalence of infection in school-age children. The common believe is that the infection rate with these children is representative for the entire community.

Diagnostics

Schistosomiasis is currently diagnosed through the detection of parasite eggs in stool or urine specimens. Eggs are detected and counted by a trained microscopist examining the filter on a glass slide. To prescribe the correct amount of praziquantel, the number of eggs in 10ml urine is counted to determine the intensity of contamination and prescribe related dosage. Accurate diagnosis is crucial to reduce risks of chronic infections.

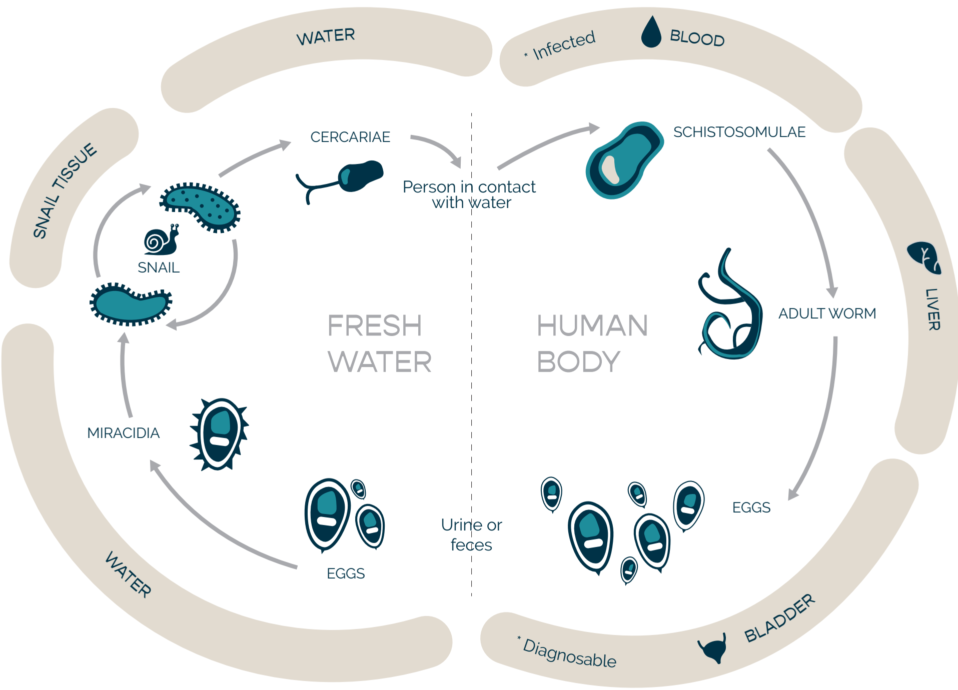


Figure 10. Lifecycle of the schistosome parasite

Estimate of 236 million
people required treatment in 2019

At least 24 000
deaths in 2019

More than 25 million
of the people requireing treatment live in Nigeria

Figure 11. Facts about Schistosomiasis

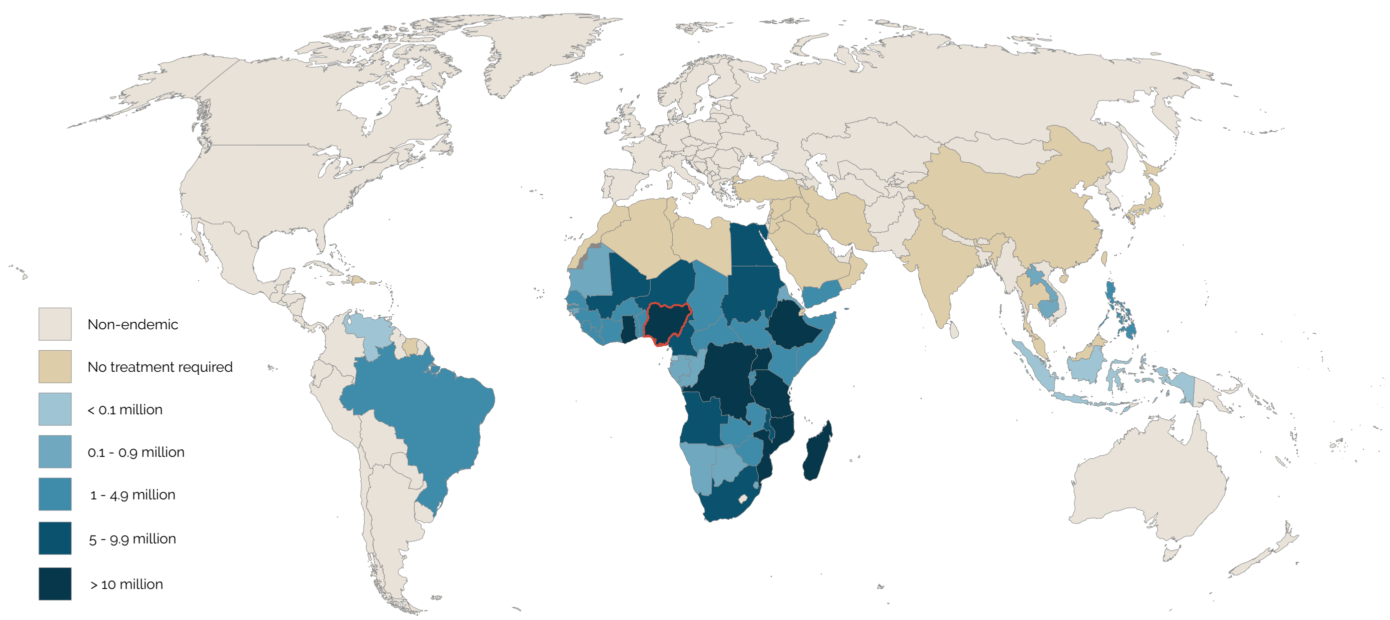


Figure 12. Global distribution of Schistosomiasis [25]

Methodology

The goal of this graduation project is to deliver a functional device to support a scientific field study. Therefore, at the end, the device must work. This makes functionality the top priority. The Schistoscope 4 is operative, however, it lacks accuracy and reliability, and both stability and embodiment that are required to transport the device to the field. A PDCA-approach is a fitting method since this project mainly focusses on improving a current situation. A PDCA-approach is useful to discover flaws of existing systems and focusses on improvement.

PDCA-approach

The PDCA-cycle is a four-step model for carrying out change and stands for: Plan–Do–Check–Act or Plan–Do–Check–Adjust. It is an iterative design method used for the control and continuous improvement of products. PDCA is considered a project planning tool and is used when starting a new improvement project, developing new products a new design of a process, product, or service [20]. One cycle of PDCA follows the steps shown in figure 13.

The aim of the PDCA-cycle, it to bring the user closer to the goals they set and adjust based on the results of the cycle. One of the principles of the PDCA-method is repetition. This is based on the belief that knowledge and skills are limited but open for improvement. Especially when starting a project, key information can only become apparent weeks after initiation. By repeating the cycle, each time proving or negating the suggested improvement, the user's knowledge on the system will extend after each cycle. With this improved knowledge, users can choose to refine or alter the goal or requirements, eventually converging towards the ultimate design.

Systems engineering

Systems engineering is a discipline of the engineering science that mainly focusses on methodical design of complex systems. The focus is on the workings of a system as a whole, the different components that make up that system, and the relation between those components.

Systems Engineering is an "Interdisciplinary approach". It manages the total technical and organizational work required to transform a set of stakeholder needs, expectations, and limitations into a solution, and supporting that solution throughout its life.

In this research project, systems engineering is used to explicitly define which goals the project aims to achieve, and what the system should be able to do to achieve those goals. Therefore, the principle of goal-function-object is used. Goals are met when certain functions are carried out, these functions are carried out by objects, certain system elements or components.

Using systems engineering, it is possible to validate whether the system as designed achieves the completion of project goals. Furthermore, it is possible to verify whether system elements satisfy the given requirements. Systems engineering in this form supports the main design method of the PDC-approach by more explicitly identifying whether the designed system satisfies the project goals.

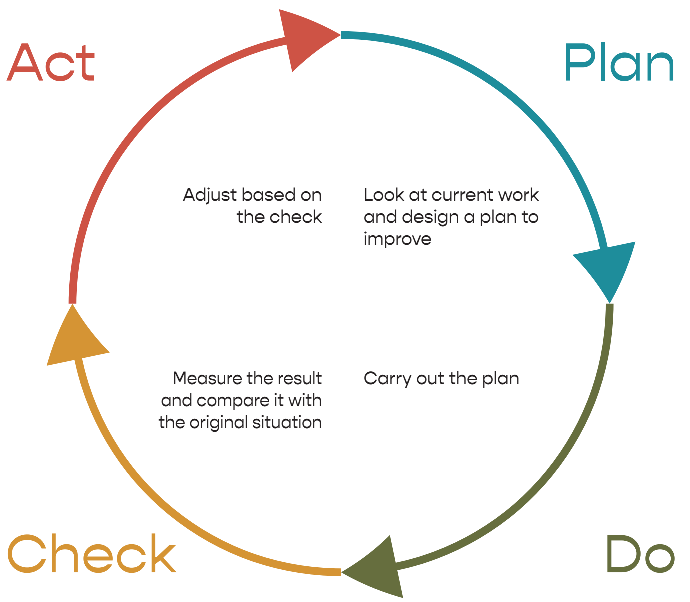


Figure 13. PDCA-cycle

Project structure

First, in the analysis phase, information is gathered to generate foundational knowledge about the project. This includes topics such as context, 3D-printing, the disease, the methods for diagnosis and the development of the Schistoscope project. The previous prototype is analysed and challenges to improve the device are created.

From the knowledge and insights generated in the previous phase, this phase defines the preliminary design requirement for a feasible and desirable product.

In the ideation and concept phase, the design challenges from phase 1 are addressed in PCDA cycles. Prototyping ideas and concepts eventually lead to a final proposed concept that integrates all the design challenges and aim for the goals stated in the design brief. During weekly user test sessions, ideas and designs are tested and improved. During the ideation process, the preliminary design requirements are constantly updated and reformulated according to generated knowledge and insights.

In the final design phase, the embodiment for the prototype is created. All systems and components are integrated into one complete design. The design is validated by the final list of design requirements and its feasibility. The focus of this phase lies with the feasibility regarding the field test. In this phase, two additional prototypes are created to support the research in the field test.

After reproducing the final design and transporting the additional prototypes towards Nigeria, the focus is with writing this thesis. Furthermore, the design is evaluated on desirability and viability. This evaluation is considered in the final recommendations.

Thesis structure

Introduction

In the first part of this thesis, the relevant background information to understand the reason behind the project is explained. It shortly introduces the stakeholders and explores a basic understanding of Schistosomiasis and its impact worldwide.

Define

In this second part of this thesis, relevant information on the diagnostic procedure, standard microscopy, context is stated. Also, the analysis of the Schistoscope development is explained and the challenges are indicated. This chapter translates the research outcomes to design requirements. Furthermore, this chapter reformulates the Project Brief into a Design Brief and the methods used in this project are explained.

Design

For the design part of the thesis, the Schistoscope is divided into sub-systems. Following the PDCA-approach, multiple design cycles are performed to come to the final design. The initial requirements are developed during these cycles towards a final list of requirements. After each cycle, the list or requirements is updated with the new requirements that resulted from the PDCA-cycle. Together with the challenges stated in the define chapter, the requirements form the foundation of this design part where they both act as guidelines towards the best design solution.

Discussion

The last part acts as a discussion on the work in this graduation project. The design is evaluated based on feasibility, viability and desirability. It also addresses preliminary outcomes of the field study in Nigeria. This evaluation is taken into consideration in the final recommendations for further development and research.

Figure 14. Project structure

Figure 15. Field test, Nigeria, 2021

2 Define

In this second part of this thesis, relevant information on the diagnostic procedure, standard microscopy and context is stated. Furthermore, the analysis of the Schistoscope development is explained and the challenges to improve the device are indicated. This chapter translates the research outcomes into design requirements. The preliminary requirements are listed in this chapter

Additionally, this chapter defines the main goal for this graduation project. From this main goal, five sub-goals are created and their importance to the project is explained.

Lastly, based on the generated knowledge, the Design Brief is created. The assignment as stated in the Project Brief (Appendix v) is to improve the current Schistoscope to a level that can execute a large field study. The original assignment has been evolved after additional research on context, device and requirements and the new assignment is formulated in the Design brief.

Diagnosis

Schistosomiasis Haematobium is diagnosed through the detection of parasite eggs in urine specimens. Urine filtration tests are fast and easy. A sample of 10mL urine is passed through a nucleopore filter (figures 16, 18). The filter is removed with a pair of tweezers and placed onto a specimen glass slide and examined under a microscope. A drop of iodine is added, and the eggs will stain orange. Hereby the eggs become visible instead of being naturally transparent.

A Schistosoma haematobium egg is 110-170 μm long by 40-70 μm wide and requires a minimal magnification of 4 for a microscopist to detect the egg. To view the entire sample, the glass slide is moved manually with a mechanic slide stable (figure 17). A trained microscopist examines the filter and counts each egg. According to WHO protocols, filters and slides should be thrown out after use However, in practice, medical staff in lower income countries usually clean and reuse the filters and slides.

Sensitivity and quality of diagnosis depends heavily on the operator and their education, which means providing diagnosis is difficult and results are questionable. Accurate diagnosis is crucial to reduce risks of chronic infections. The WHO roadmap has indicated the development of diagnostic tests as one of the critical actions to achieve the set targets [26].

In most of the endemic areas there are only a few medical trained staff members, who can perform such diagnostics. Furthermore, microscopy is exhausting work, sensitive to errors and requires electricity, which is presumably absent in those endemic poor and rural communities where hygiene is insufficient and infection rate is high.

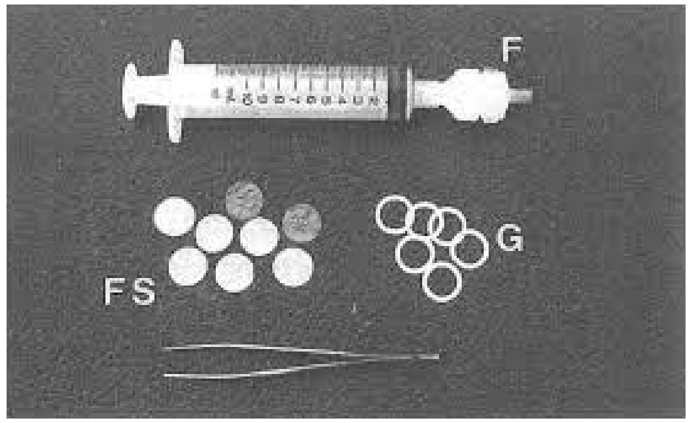


Figure 16: Instruments required for sample preperation


Figure 17: Microscopist examining a sample slide, Nigeria, 2020

System requirements on the aspect of diagnosis

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm

2 The glass slide should maintain position of a urine filter

3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide

4 The device must allow for a change of glass slide

5 All materials used for the device must sustain their physical properties after being cleaned by alcohol

6 The device must allow for the use of a 4X microscope objective


Figure 18: Syringe filtering a urine sample


Figure 19: Collected samples, Nigeria, 2020

Microscopy

Microscopes are used to view, magnify and produce images from different types of specimens. It exists of the parts as shown in figure 22. The following parts are changed in the translation towards the Schistoscope:

1. Eyepiece is replaced by a camera
2. Adjustment knobs are replaced by automated linear movement system and software-based auto focus
3. Mechanical stage is replaced by automated movement systems

Depth of Field

The Depth of Field (DoF) of an optical set-up is the distance between the nearest and the farthest objects that are in acceptable focus in an image (figure 20). If the system is focus on a certain object, but the object to be examined is not within the current DoF, the system should refocus, moving either up or down, in included the required object in a new DoF [17].

Depth of Focus

Due to similarity in name, depth of field and depth of focus are commonly confused terms. DoF refers to the area in front of the lens in acceptable focus. Depth of focus refers to the area behind the lens, towards the sensor, to capture an in-focus image [7]. Microscope objectives have specific (depth of) focus lengths. These specifications are listed on the body of the objective [8] (figure 20). The Schistoscope uses a 4X magnification with a (depth of) focus length of 160mm.

Focal point

The illumination set-up uses aspheric condenser lenses to illuminate the sample. These lenses have a focal length, at which the light beam converges to one point, the focal point. To adequately illuminate the sample, this focal point should not be on the surface of the glass slide, or on the sample, but a bit further away from the sample, see figure 20. This will ensure adequate contrast and resolution in the captured images [22].

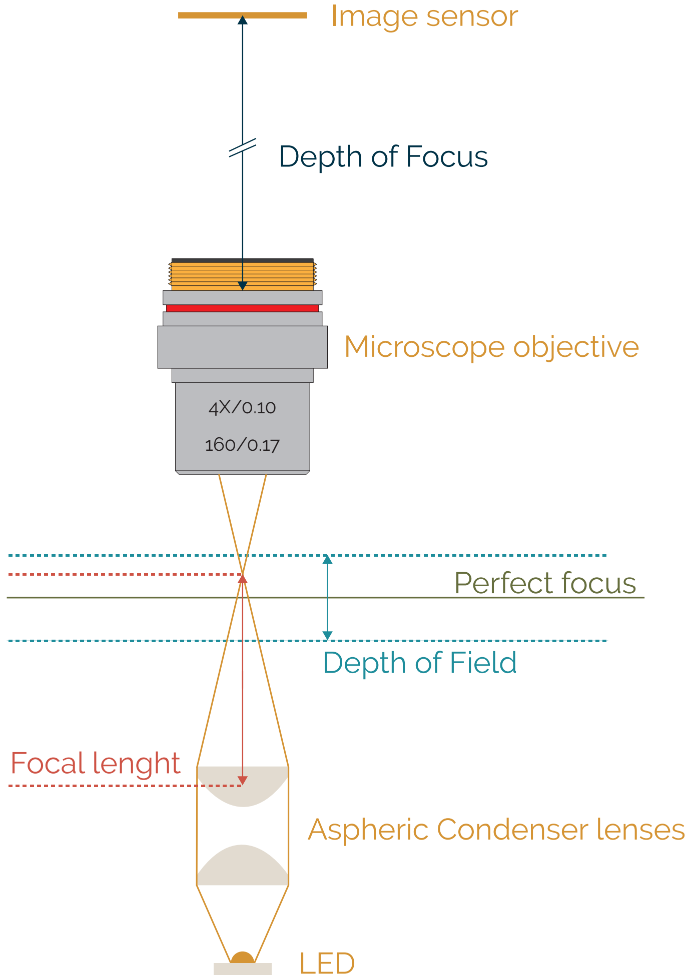


Figure 20. Depth of Focus, Depth of field and Focal point


Figure 21.: Schistosomiasis Haematobium egg

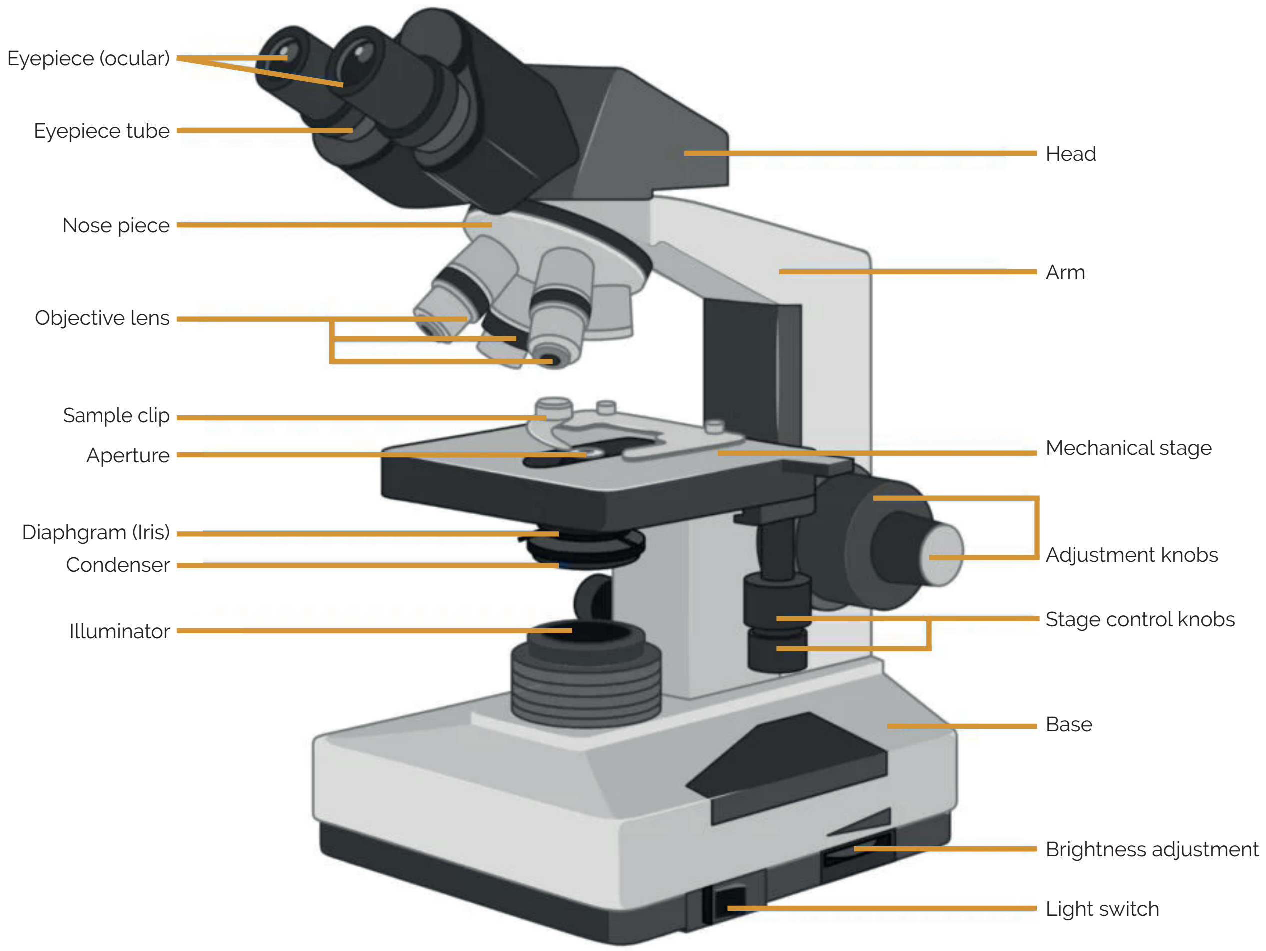


Figure 22. Parts of a Microscope [15]

System requirements on the aspects of a microscopic system

7 The device must adequately illuminate the sample

8 The device must allow for the use and change of a microscope objective

9 Systems and components must move according specific relations

10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm

11 The device must allow for levelling of the sample bed

Context

The two PhD candidates connected to the INSPiRED project, Brice Meulah from LUMC, and Prosper Oyibo from TU Delft will carry out a 'proof of concept' study to evaluate the Schistoscope 5. The study includes validation of the developed AI for the detection and quantification of Schistosomiasis Haematobium eggs, by using standard microscopy as a reference standard. The AI will run on a small developer computer inside the device.

During the laboratory field research in Nigeria, the researchers will collect 400 urine samples from a study population with an estimated 25% prevalence. The aim is to collect approximately 100 urine samples that are positive with at least one Schistosomiasis Haematobium egg per 10ml of urine.

Each sample will be prepared as described before and will be read by two independent readers, one will use a standard microscope, the other will use the Schistoscope. The samples will be imaged using 4x magnification in the Schistoscope 5 device with an automated X-Y axis directional sample movement and focusing mechanism. The images will be captured by a camera sensor and analysed for the presence or absence of Schistosomiasis Haematobium eggs by the AI algorithm. The system will report the number of eggs detected in the sample and are recorded by the device operator.

To evaluate the performance of the automated Schistoscope 5.0 coupled AI for the detection of Schistosomiasis Haematobium eggs in urine-filtered slides with standard microscopy as a reference."

PhD research goal

System requirements on the aspects of the context

12 The device must allow for the use of a Jetson Nano Developer board

13 The device must allow for the use of a Jetson Nano Camera

14 The device must be reliable

15 The device must operate in climate temperatures of at least 50 degrees celcius

Figure 23: Sample collection Nigeria, 2020

Figure 24. Sample preperation, Nigeria, 2021

Figure 25. Schistoscope 4 during fieldtest in Nigeria, 2020

Schistoscope 4

This chapter analyses the current Schistoscope 4 and addresses the main challenges to improve the design to the desired quality. The challenges will be part of the formulated goals in chapter Design Brief and used to validate the final design.

Challenge 1: Improve the stability and fixation of the camera

The Schistoscope 4 uses magnets to fixate the camera onto the tube. These magnets are not a precise connection, they allow for slight movement of the camera, which causes inaccuracy in the images. Vibrations of the motor or other movements trigger the camera to change position, while staying connected to the magnets. As temporary solution a piece of tape was attached to the tube to prevent the movement (figure 26).

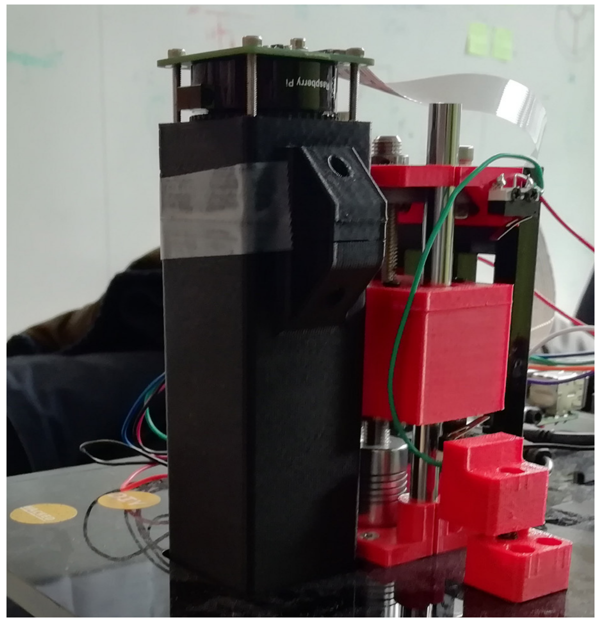


Figure 26. Camera tube Schistoscope 4

Challenge 2: Include illumination unit into the optical system

The research group has provided an illumination set-up which must be included in the device. As explained in chapter Microscope, the illumination is part of the optical set-up, and affects the quality of the images. The illumination unit and its position must meet specific requirements and relations within the optical set-up.

Figure 27. Provided design Illumination unit

Challenge 3: Allow for different Field of View of sample

The Schistoscope uses a camera sensor to capture the magnified images. This sensor captures only a small part of the entire sample per captured image. The area that is captured by the sensor is called the Field of View (FoV). Capturing the entire sample entails capturing multiple FoV, according to a grid pattern (figure 28). Where in standard microscopy the operator manually examines the entire sample, the Schistoscope has automated sample movement. This means that the device automatically changes the FoV that is captured by the camera. The Schistoscope 5 must have a sample movement to allow all FoV to be captured.

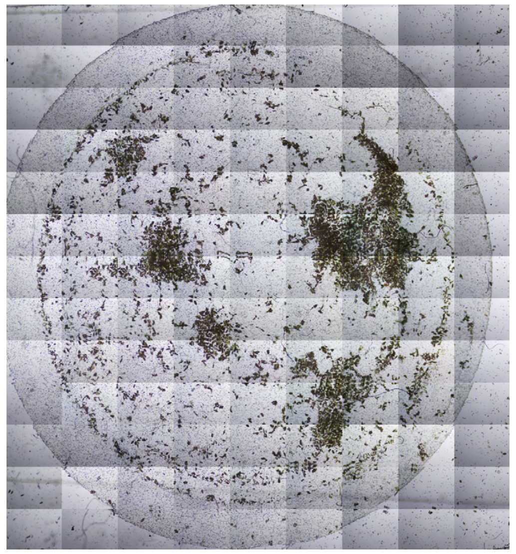


Figure 28. Image results of Schistoscope

Challenge 4: Ensure consistent Field of View

Where the Schistoscope 4 allows for different FoVs, it lacks consistency and reliability when the sample is moving around. Ensuring a consistent FoV is important to ensure capturing the entire sample and providing the complete egg count. Inconsistencies in the Schistoscope 4 are due to a lack of precision in the automated linear sample movement and the glass slide changing position. As temporary solution a piece of tape was attached to the glass slide to prevent the movement (figure 29).

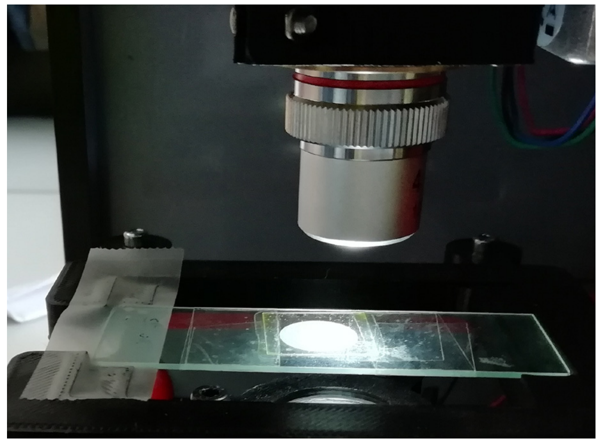


Figure 29 Sample in Schistoscope 4

Challenge 5: Provide stability of all systems inside the device

The Schistoscope 4 lacks stability. The preview image on the display and thus the captured images trembles when the surface on which the prototype is placed vibrates. This can happen when people walk by close to the device or the user types on a keyboard on the same surface.

This is a major issue, since the device will automatically scan the entire sample for a duration of 20 minutes. Large displacement due to vibrations can affect the image that is captured, condemning the entire scan. The prototype is currently placed on bubble wrap, figure 32, reducing influence from external vibrations. However, the final design should provide the required stability and prevent such large displacements.

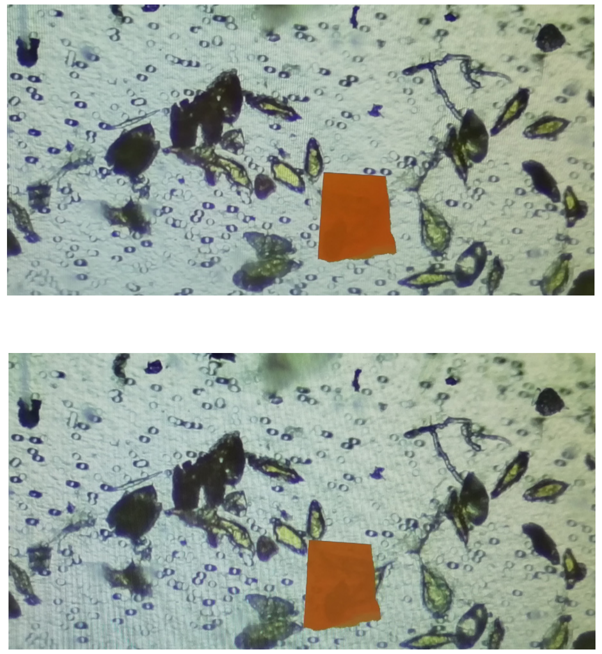


Figure 30: Change in image preview Schistoscope 4

Challenge 6: Create a barrier between the systems and the environment

The Schistoscope 4 has not been taken to the field. The device is only tested in relatively normal environments, at home or at the IDE faculty. Therefore, there is no real need for an enclosure to protect the device from environmental impacts, like dust, sand, or water. However, the Schistoscope 5 will be taken to the field. It will be transported to a Nigerian laboratory, which has different environmental conditions than Dutch universities. Therefore, the Schistoscope 5 needs an enclosure system that protects the systems inside the device from the Nigerian conditions.

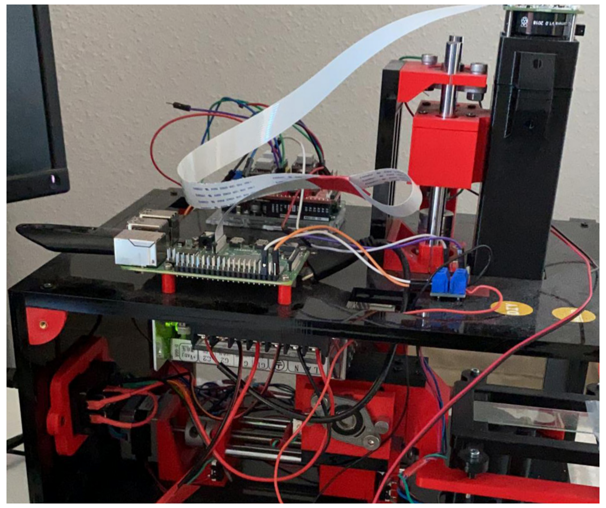


Figure 31 Schistoscope 4

System requirements on the aspects of the Schistoscope

16 The device must provide stability to the integrated systems

17 The device must house specific electronic components

18 The device must have a robust appearance

19 The device must enable automated x, y and z movements

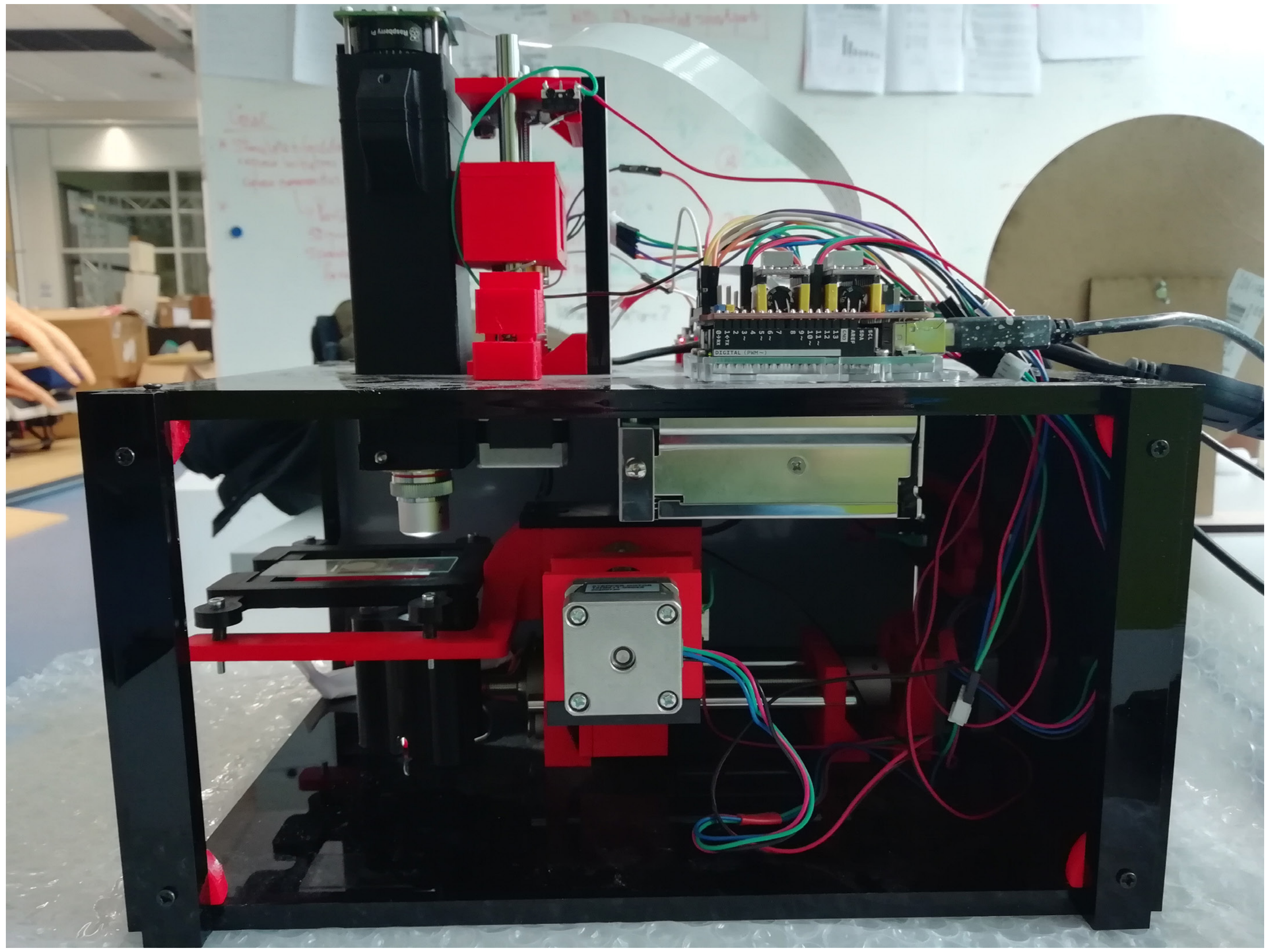


Figure 32. Schistoscope 4

Two year history of the Schistoscope

Figure 33. Schistoscope AED team A, 2019

Figure 34. Schistoscope AED team B, 2019

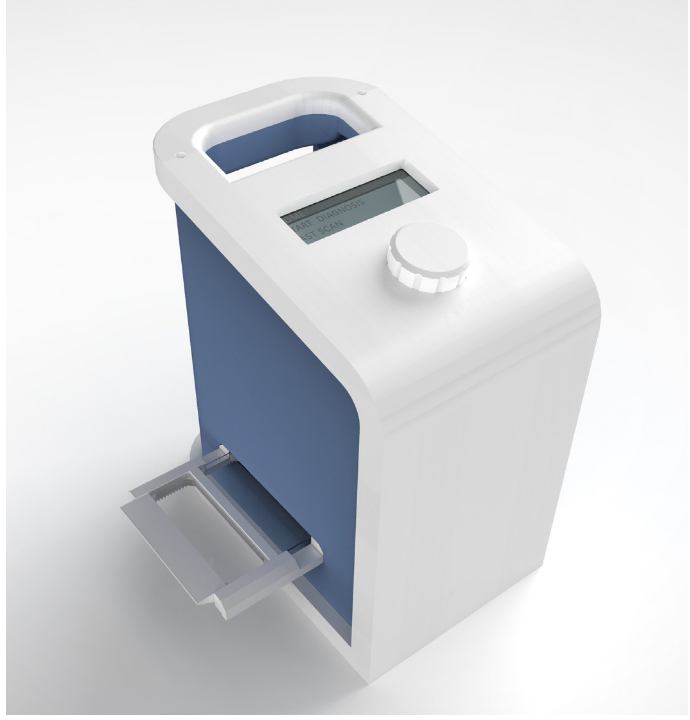


Figure 35. Schistoscope AED team B, 2020

Figure 36. Schistoscope AED team B, 2020

Figure 37. Technical Schistoscope 3A 2020

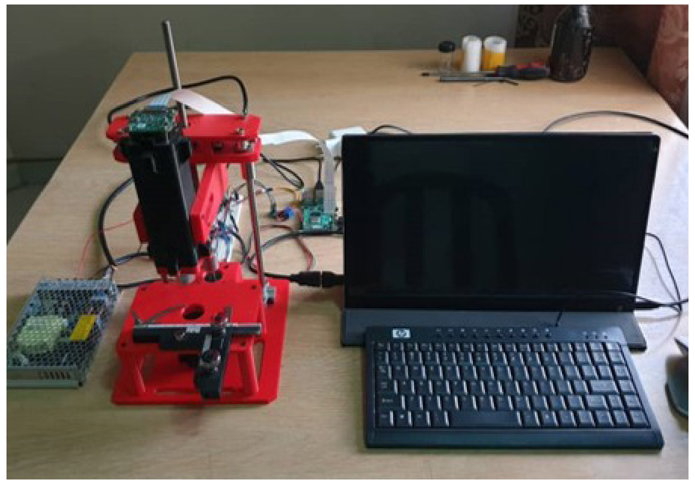


Figure 38. Technical Schistoscope 3B, 2020

Envisioned Schistoscope

The aim of the Schistoscope project is to develop a low cost, smart diagnostic device. Ideally, the Schistoscope can be locally manufactured and repaired, by using locally available materials and manufacturing processes. This will make the Schistoscope accessible to the last mile health care providers. The Schistoscope will be designed to be used with limited expertise, thereby increasing the accessibility of the device [6]

Future developments on the Schistoscope will focus on translating the outcome of this graduation project into a viable and desired design, that fits the needs of the stakeholders involved. Recent studies have brought up important requirements for the Schistoscope to become viable. One important requirement for the device is that it must be deployable to distant communities. This includes design for transportation on motor bikes, cars and on foot. That also includes that the device must be portable and have a high reliable power source which is independent off the local power net [10].

The recent study also addresses the need for local repair and maintenance. The continuous Schistoscope project explores open-source possibilities to improve accessibility. Furthermore, integrating local manufacturing by using 3D-printing possibilities in local universities and maker labs are investigated. 3D-printing is considered an easy, fast, accessible and cheap manufacturing method. Currently, 3D-printing machines are available in low-income countries for a good price. The method allows for rapid prototyping with an unprecedented level of freedom [5]. Within this graduation project, 3D-printing is considered as main production method as well, allowing for easy transition towards a scalable design that is manufacturable in low-income countries.

In the past years, many Schistoscope projects have focussed on creating a desirable and viable design. Page 25 shows the most recent design iterations from the past two years. Figures 33-36 are part of the Advanced Embodiment Design course, from the master Integrated Product Design. Each design revealed promising insights and solutions to different problems and aspects. However, those designs did not meet the desired quality of images and reliability. Therefore, in the last year, the Schistoscope project has been developing technical prototypes, see figure 37 and 38. These prototypes mainly focus on functionality instead of other design aspects.

The project has expressed their desire to improve these technical prototypes into a completely functional prototype before including looks and design. A feasible design is applicable in scientific research and publications. After ensuring the principles to the scientific community, next iterations on other desirability and viability can be executed.

The INSPiRED project group addressed their wish for an integrated, functional prototype, which can be redesigned in a next phase to fit all viable requirements. Therefore, this graduation project will focus mainly on the requirements that add to a functional device, while keeping in mind the requirements and wishes for the envisioned Schistoscope, such as 3D-printing and local production, low price and transportation possibilities.

Desirable qualities of the future Schistoscope

1. The device must be portable to distant communities
2. The device must be as cheap as possible
3. The device must be produced locally in Nigeria
4. The device must allow for repair and maintenance
5. The device must have a reliable internal power source

Initial list of Requirements

1. *The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm*
2. *The glass slide should maintain position of a urine filter*
3. *The device must be able to scan the entire 13 mm filter placed at any position of a glass slide*
4. *The device must allow for a change of glass slide*
5. *All materials used for the device must sustain their physical properties after being cleaned by alcohol*
6. *The device must allow for the use of a 4X microscope objective*
7. *The device must adequately illuminate the sample*
8. *The device must allow for the use and change of a microscope objective*
9. *Systems and components must move according specific relations*
10. *The distance between the camera sensor and the bottom of the objective thread must be 160 mm*
11. *The device must allow for levelling of the sample bed*
12. *The device must allow for the use of a Jetson Nano Developer board*
13. *The device must allow for the use of a Jetson Nano Camera*
14. *The device must be reliable*
15. *The device must operate in climate temperatures of at least 50 degrees celcius*
16. *The device must provide stability to the integrated systems*
17. *The device must house specific electronic components*
18. *The device must have a robust appearance*
19. *The device must enable automated x, y and z movements*

Design brief

Main goal

The overall goal of this graduation project is to provide the research group with the Schistoscope 5, to support a field-test in Nigeria. For the field-test to be successful, the Schistoscope 5 must facilitate an effectively captured sample. Therefore, the device must provide qualitative image results of the sample. This is the main goal of the Schistoscope 5.

The main goal is divided into five smaller goals. These sub-goals are more detailed to specify the required functions of the Schistoscope 5. The sub-goals add to the previous stated challenges to improve the design of the Schistoscope. By completing the challenges, the design will achieve the stated goals. The challenges and goals form a guide in the design process and help validate the final design.

Figure 39. Main project goal

Figure 40: Sub-goals, function and object

Goal 1: Effectively captured qualitative images

The Schistoscope 5 needs to effectively capture qualitative images to ensure that the AI provides reliable results. If the images captured by the device differ from the AI standards, the algorithm cannot detect eggs and therefore not provide the user with an egg count. These AI standards are based on contrast, colour balance and resolution. The quality should be close to the quality of the images captured by the Schistoscope 4, since the AI was trained on images taken by this device.

To effectively capture qualitative images, the device must provide a sample image. This function is carried out by the optical system. The optical system must meet the requirements as stated in chapter Initial list of Requirements. Additionally, included in the optical system, there should be a light beam directed unto the sample. This function is carried out by the illumination unit. The design of the illumination unit is out of scope, however, the position of this unit within the device is included in the scope of this graduation project.

Challenge 1: Improve the stability and fixation of the camera.

Challenge 2: Include illumination unit into the optical system

Goal 2: Entire sample captured

To ensure that the AI provides a complete egg count result, the Schistoscope 5 must capture the entire sample, capturing all eggs. Therefore, the device must allow for different field of views, that are consistent and reliable. This function is carried out by the sample moving system, that allows for a change of position of the sample slide relative to the optical system, to create different Field of Views of the sample. However, this goal is also affected by inconsistencies in the optical system.

Challenge 3: Allow for different Field of View of sample

Challenge 4: Ensure consistent Field of View

Goal 3: One integrated robust prototype

The Schistoscope 5 will be transported to a Nigerian laboratory and potentially to different locations in Nigeria. Therefore, it is important that the device is an integrated robust device. All systems should be integrated into an enclosure that serves as a barrier between the device, its internal systems inside and the environment outside.

Challenge 5: Provide stability of all systems inside the device

Challenge 6: Create a barrier between the systems and the environment

Figure 41. Schistoscope 5

3 Design

This chapter is structured by the PDCA approach explained in chapter Methodology. It chronically addresses the cycles passed during this graduation project. Keep in mind that these cycles are used to narrow down the specific needs for this project, therefore, statements, assumptions and requirements differ throughout this thesis, since they evolved during the graduation project.

As explained in the previous chapter, the cycles will start with stating a plan to take-up certain challenges. Each cycle uses the requirements from the previous visualised, most recent list. The execution of the plan is described in the 'do' section. Next, the results are verified and validated in the 'check' section, after which a short conclusion and action is described in the 'act' section. After each PDCA-cycle, the requirements list is updated.

Reading guide

When reading the design chapter, it is important to understand that the execution of the PDCA-cycles did not happen as chronically and linearly as they are presented in this thesis. Often, multiple cycles were performed simultaneously, influencing and supporting each other. Figure 42 shows how the cycles approximately have been performed.

Cycle 1 and 2 are exploring the relations and the initial requirements of the Schistoscope. During these cycles, initial ideas and solutions are created and the three concepts are presented, as they were presented during the midterm of the graduation project.

From cycle 3 to 5, one of the concepts is enhanced and detailed. The first working prototypes are created and tested with the software. The fifth cycle initiates the shift from the first conceptual prototype towards the final design.

Cycle 6 to 11 are about the internal systems of the device. The cycles happened simultaneously and supported each other.. The cycles present the final solutions of this graduation project and a short explanation into why this solution was chosen.
After the internal systems were defined, cycle 11 and 12 address the embodiment of the final design of the Schistoscope 5.

In order to understand the full process of this graduation project, it is recommended to read this entire chapter. For a complete explanation of the final design, cycle 6 to 12 are recommended.

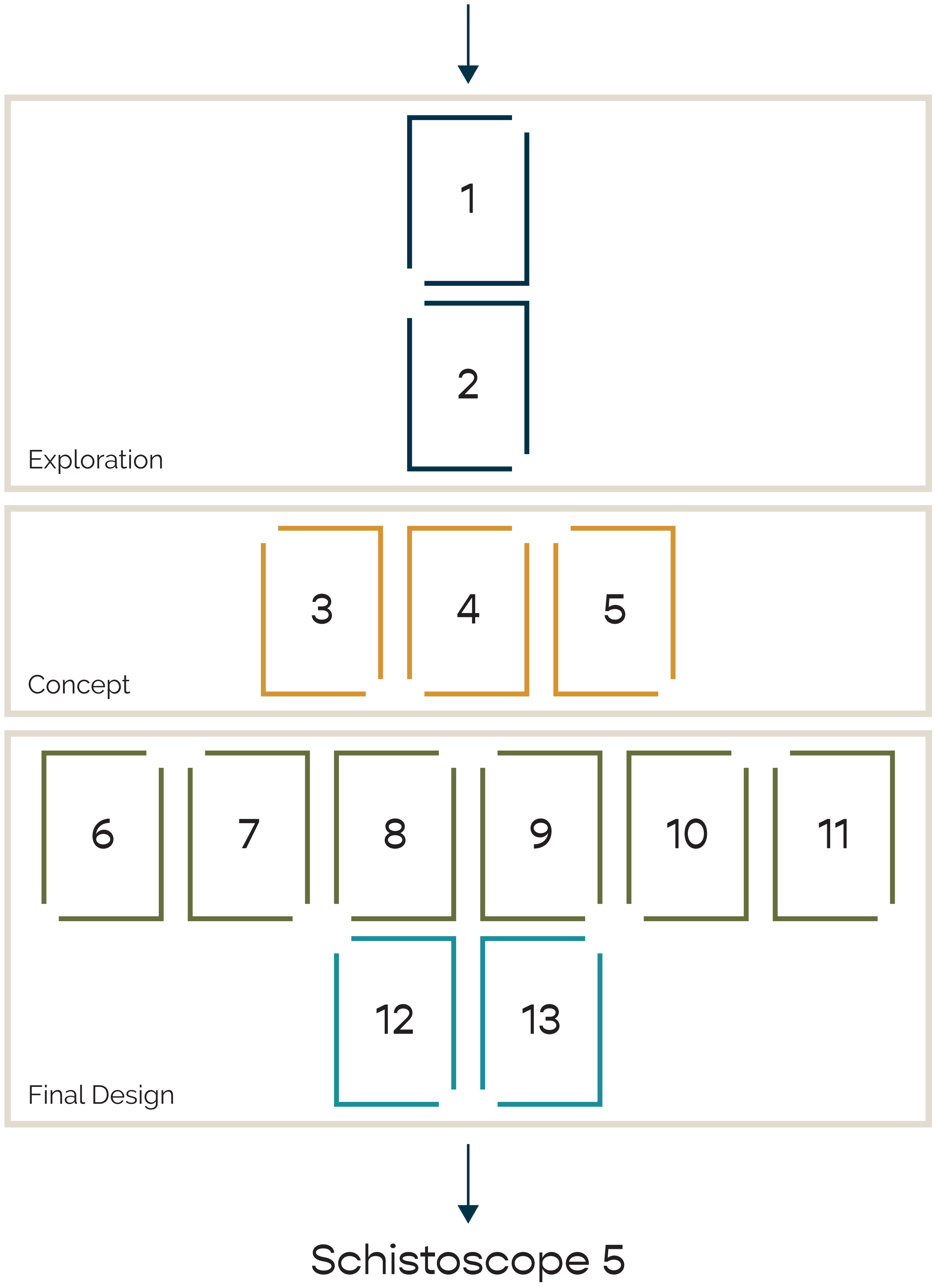


Figure 42. PDCA-reading guide

PDCA-1

Relative movements

Plan

To start the design process, an understanding of the relative movements of all systems and its components must be created. By analysing the Schistoscope 4 and the use of a method called tinkering [14], the possible combinations of movements and thus their relations are visualised. This understanding of the relation of components to each other helps to create ideas and solutions in the next cycles. This cycle focusses on the elaboration of requirement 9 of list 1.

Figure 43.: Exploration relative movement

Direction	Stationary Camera sensor	Stationary Sample	Stationary Illumination
Z-axis	Sample Illumination	Camera sensor	Camera sensor
X-axis	Sample	Camera sensor Illumination	Sample
Y-axis	Sample	Camera sensor Illumination	Sample

Table 2: Stationary relations

Do

Three different components require movements relative to each other. Firstly, the camera sensor that captures images. Secondly, the sample slide that holds the filter which needs to be captured. Thirdly, the illumination at the bottom, that illuminates the sample slide and directs light beams onto the camera sensor. Appendix F provides more images of the process that provided the insights of the relative movements.

Table 1 and figure 44 show which components of the moving systems must move together and which must be stationary relative to each other. For example, in the Z direction: either the camera sensor or the sample must move to allow for focus. However, the illumination and the sample must never move in the focus direction, their distance must be stationary. Furthermore, there is no relation between the illumination and the camera sensor in the focus direction.

Table 2 shows the relative movements. It shows which components move along an axis if one of the components is stationary. For example, in the Schistoscope 4, the illumination is stationary. Therefore, the camera sensor must only move in the focus direction, in this case, the z-axis. The sample must remain in the same position on the z-axis but must move in both x- and y-axis, to capture the entire sample. These relations are used during ideation and conceptualisation.

Check

Based on these relations, the system requirements are updated to more accurate and detailed requirements. The requirements are listed in list 2.

Act

The new requirements must be taken into the next PDCA cycle, to explore directions and possible design while maintaining the relative movements.

Direction	Component A	Component B	Function
Z-axis	Camera sensor	Sample	Focus
Z-axis	Illumination	Sample	No movement, Fixed distance
Z-axis	Camera sensor	Illumination	No relation, but changes because of focus
X-axis	Camera sensor	Sample	Next Field of View
X-axis	Illumination	Sample	Next Field of View
X-axis	Camera sensor	Illumination	Stationary position
Y-axis	Camera sensor	Sample	Next Field of View
Y-axis	Illumination	Sample	Next Field of View
Y-axis	Camera sensor	Illumination	Stationary position

Table 1: Relative movments

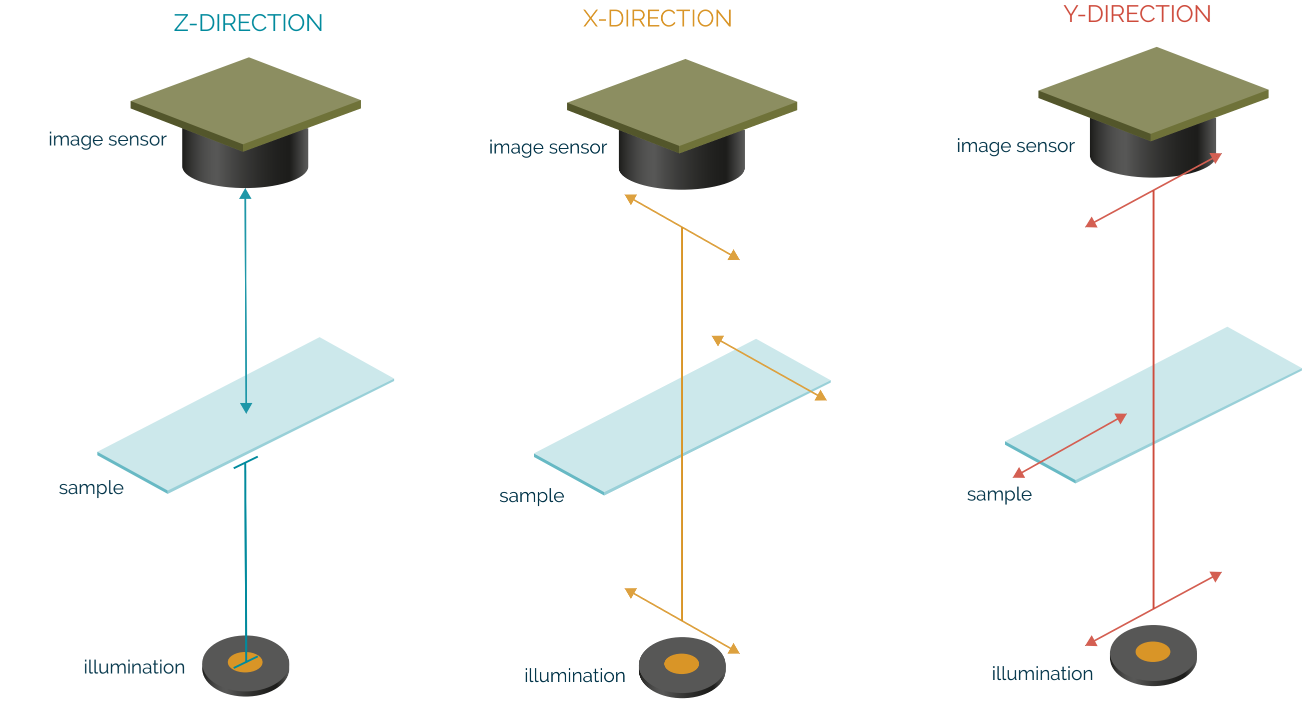


Figure 44: Relative movements

List of Requirements 2

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm

2 The glass slide should maintain position of a urine filter

3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide

4 The device must allow for a change of glass slide

5 All materials used for the device must sustain their physical properties after being cleaned by alcohol

6 The device must allow for the use of a 4X microscope objective

7 The device must adequately illuminate the sample

8 The device must allow for the use and change of a microscope objective

9 Systems and components must move according specific relations

9.1 Either the camera sensor or the sample must move in the focus direction, z-axis

9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis

9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis

9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis

9.5 Either the illumination or the sample must move in the short sample direction, x-axis

9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis

9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis

9.8 Either the illumination or the sample must move in the long sample direction, x-axis

9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis

10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm

11 The device must allow for levelling of the sample bed

12 The device must allow for the use of a Jetson Nano Developer board

13 The device must allow for the use of a Jetson Nano Camera

14 The device must be reliable

15 The device must operate in climate temperatures of at least 50 degrees celcius

16 The device must provide stability to the integrated systems

17 The device must house specific electronic components

18 The device must have a robust appearance

19 The device must enable automated x, y and z movements

Unchanged | *Added* | *Adapted or removed requirement*

PDCA-2

Ideation and concepts

Plan

The plan for this PDCA-cycle is to ideate on the challenges mentioned in chapter Design Brief and create three promising concepts to solve these challenges. Challenges 1 and 3 are considered for this cycle. They focus on how to improve the stability of the z-axis movement to ensure consistency in Field of View (FoV) when moving up and down to focus, and how to improve the stability and fixation of the camera.

Challenges

Challenge 1: Improve the stability and fixation of the camera

Challenge 3: Ensure Consistent field of view

Do

An ideation session on moving a tube upside down provided four feasible and promising ideas. These four ideas were worked out in detail, paying attention to how they can be integrated with the other components and systems. They formed the base for 3 concepts.

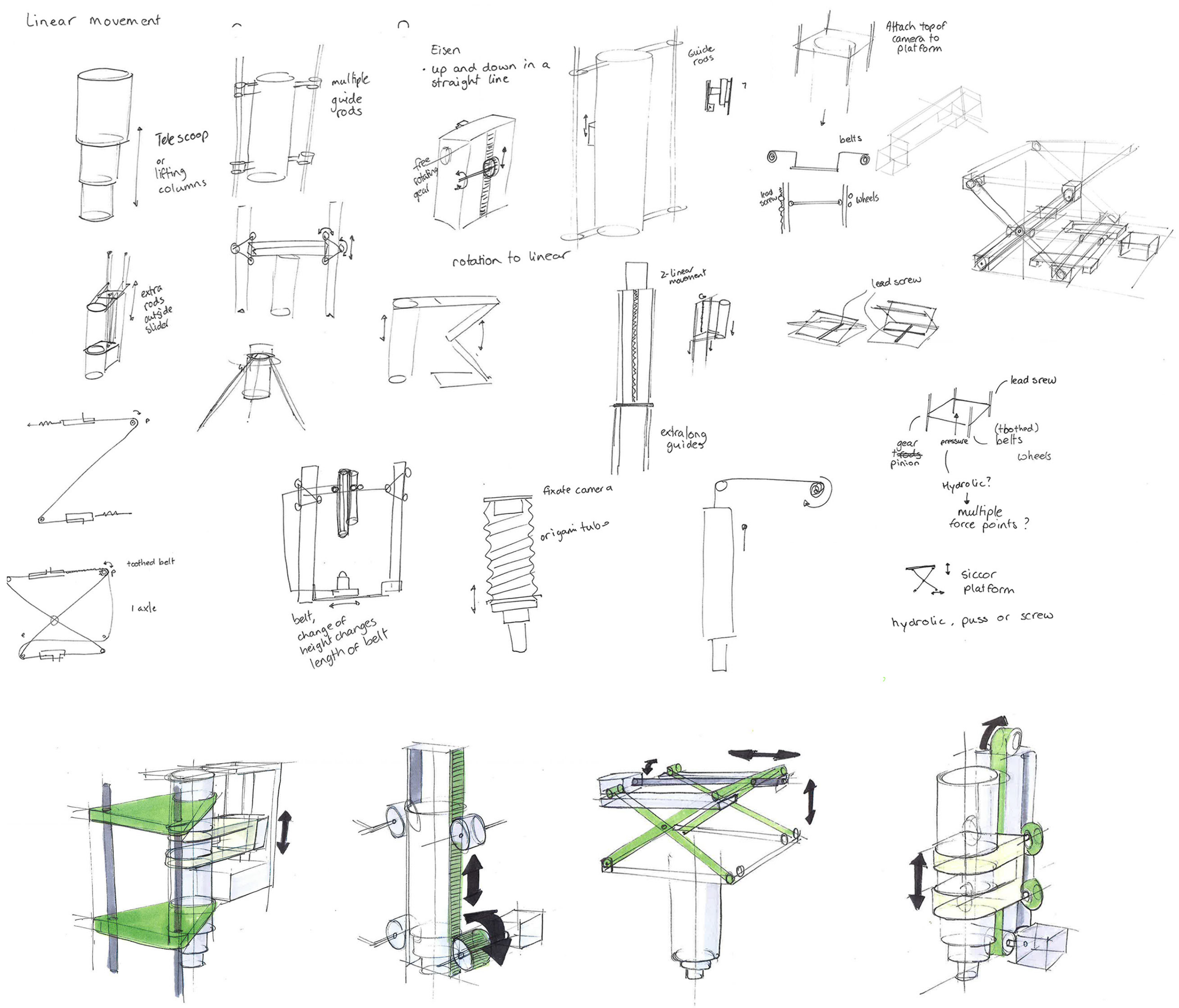


Figure 45: Ideation on z-movement

Concept 1

This concepts applies a sciccor lift table mechanism to combine the movement of the sample and the illumination. The optical train is entirely stationary, thus all moving components are at the bottom of the device. This contributes to a stable device. The illumination unit must also be fixated on the surface of the scissor table, along the x-y sample movement system. The glass slide must move along x and y, for example with a similar system as the Schistoscope 4.

- + Close to Schistoscope 4.0 proven principles
- + Strong and rigid
- + Precision sufficient for 4X
- - Improvement instead of innovation

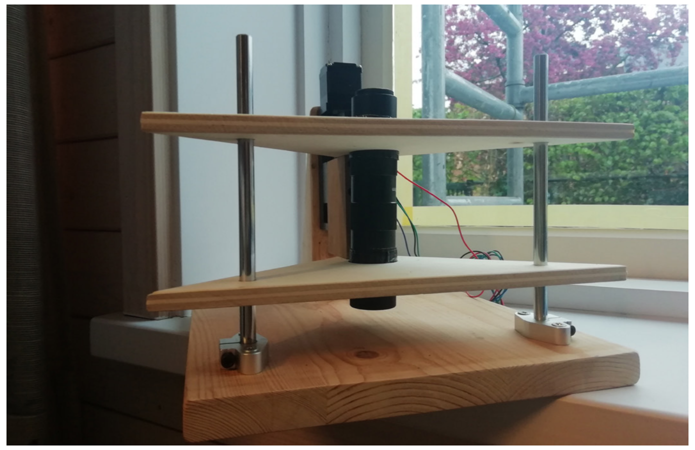


Figure 46: Concept 1

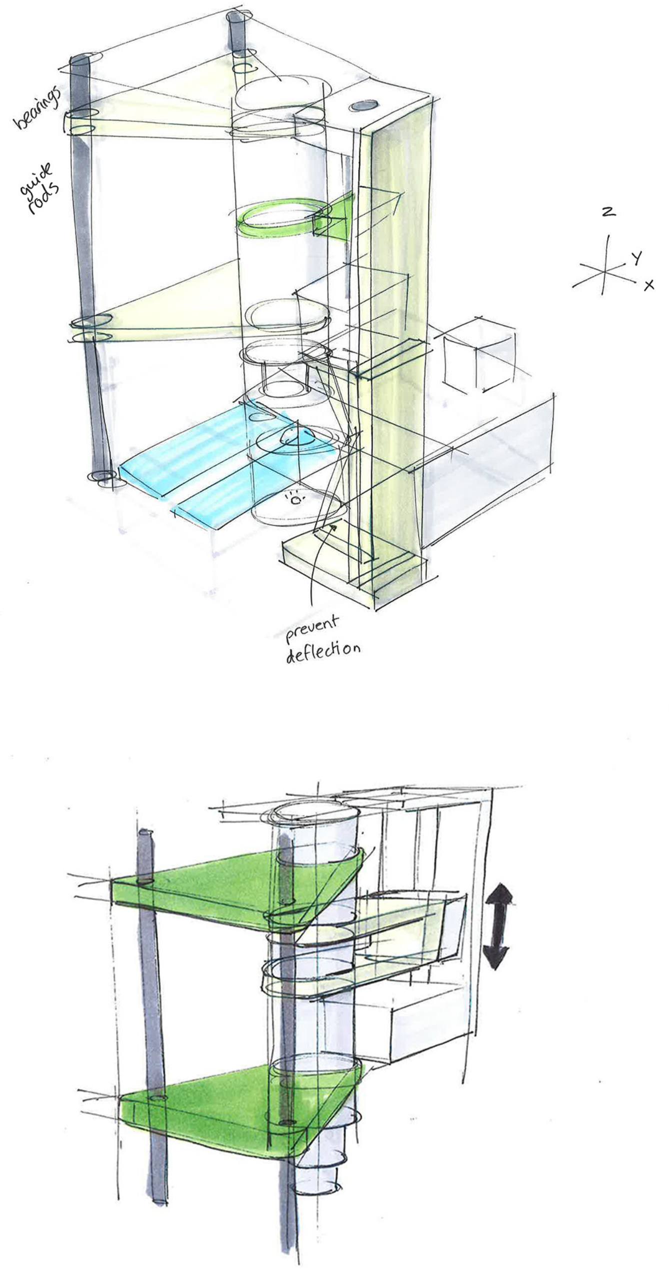


Figure 47. Sketches Concept 1

Figure 48. Concept 1

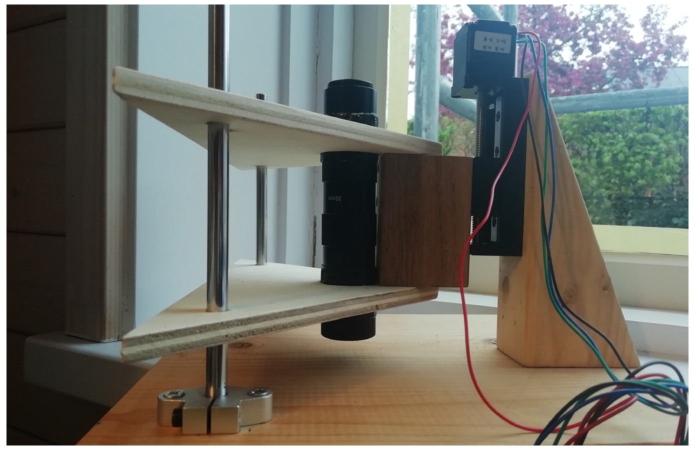


Figure 49. Concept 1

Concept 2

This concept is a direct improvement of the Schistoscope 4. It applies the same principles and elements, although the movements are more supported and guided. Two guide rods are added to restrict the optical train from moving in any other direction than the z-direction. This concept uses an off-the-shelf stepper motor slider, which holds two horizontal plates that mount a tube. At the top of the tube, there is an external screw thread to screw on a camera, and an adapter ring to screw on a microscope objective. The stability of this concept is sufficient for a 4 and 10x magnification.

- + Microscope principle
- + Siccor table is widley used in other fields
- - New translation, new challenges
- - Unknown precision
- - Complexity

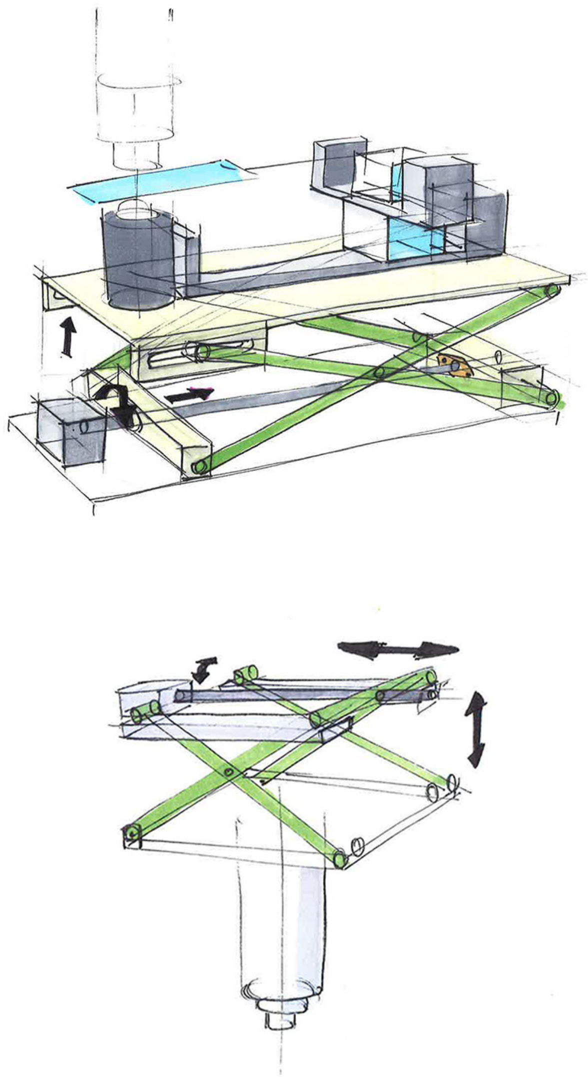


Figure 50. Sketches Concept 2

Figure 51. Concept 2

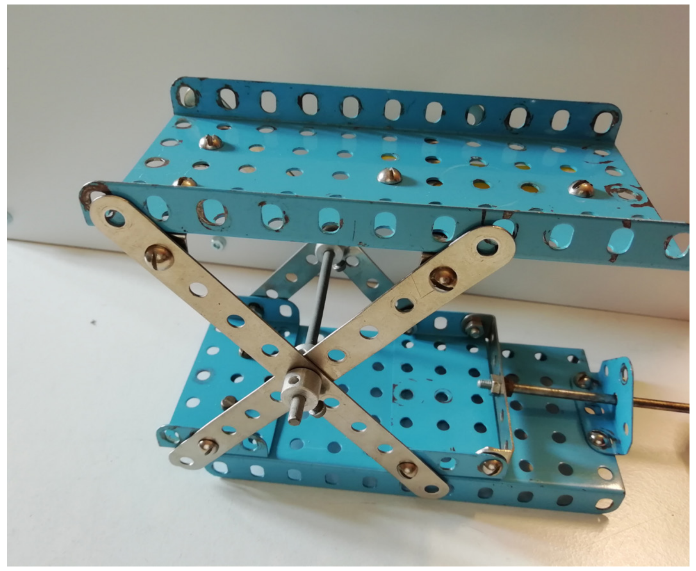


Figure 52. Concept 2

Concept 3

The third concept places the glass slide vertically instead of horizontaly, allowing the optical train to be placed horizontally at the bottom. A valuable solution, since the optical train is most likely the heaviest system of the three systems, and the stability of the device will improve if the movemnt of this heavy weighted moving system is at the lowest point possible. The illumination unit is stationary, and horizontal aswell. The glass slide will move up and down from a surface that moves left and right. Using a screw thread with a stepper motor on one side of the sample, the sample is pushed up and down. At theother end of the sample, a guide rod will prevent the sample from rotating.

+ Camera sideways
+ Flat device set-up
- New sample preparation

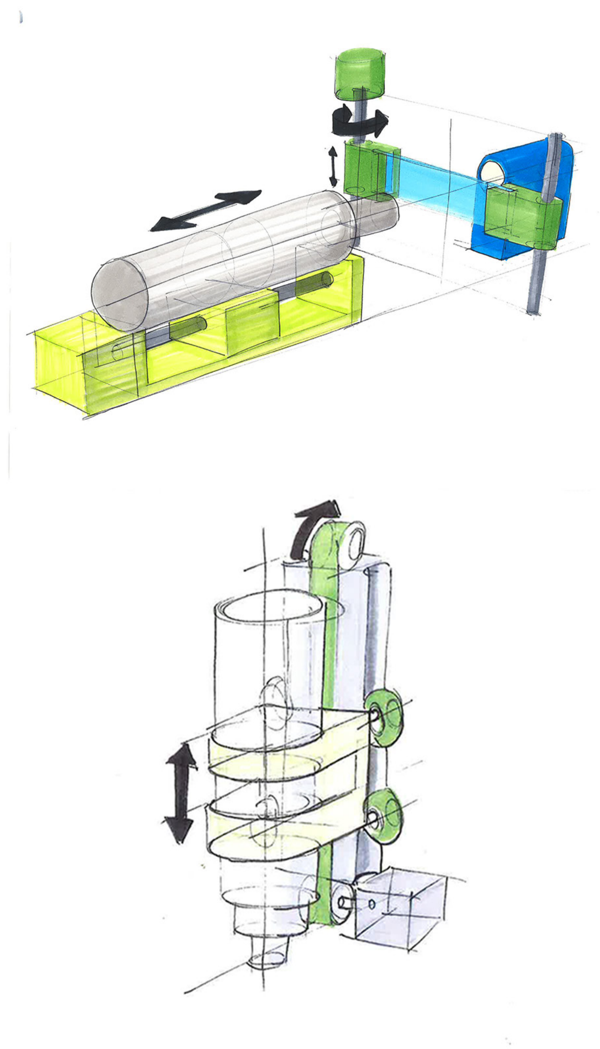


Figure 53. Sketches Concept 3

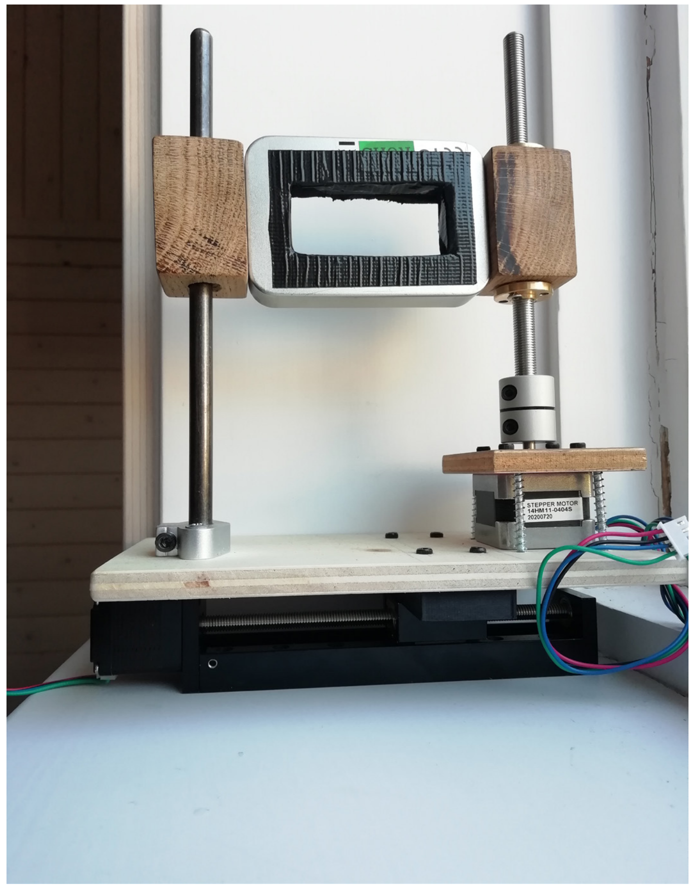


Figure 54. Concept 3

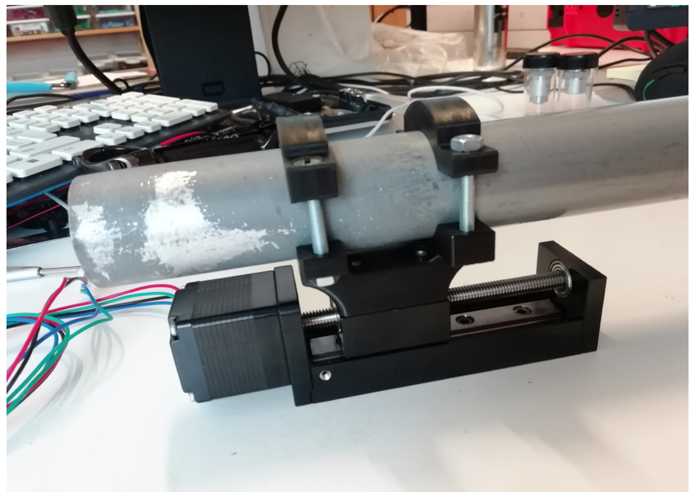


Figure 55. Concept 3

Check

All concepts were presented and discussed with the research team. In figure 56, the concepts are ranked on certain factors.

Normally it could be argued that these last two factors should be more important, however, the focus of this project lies with feasibility, and must deliver in a short time frame. Therefore, the team stated their preference towards a straightforward and feasible design. Therefore, concept 1 is selected to continue in the next PDCA-cycle.

Act

All concepts meet the requirements of list 2, but during the development of the concepts, new requirements are identified. These are listed in list 3. In the next PDCA-cycle, the chosen concept must be detailed further. In separate cycles, sample placement and embodiment should be addressed.

Feasibility	The final product must be feasible, since it will travel to the field.
Stability	The device works on microscopic precision, and stability of the device will improve the accuracy and quality of the results.
Acceptability	Does the concept use commonly accepted methods or does it deviate from the standards
Precision	Precision and reliability address the need for precise movements that are controllable by the software
Challenging	Is the concept challenging the designer or is it a safe direction.
Innovative	Is the concept new and innovative and does it add value for users

Table 3: Scoring aspects

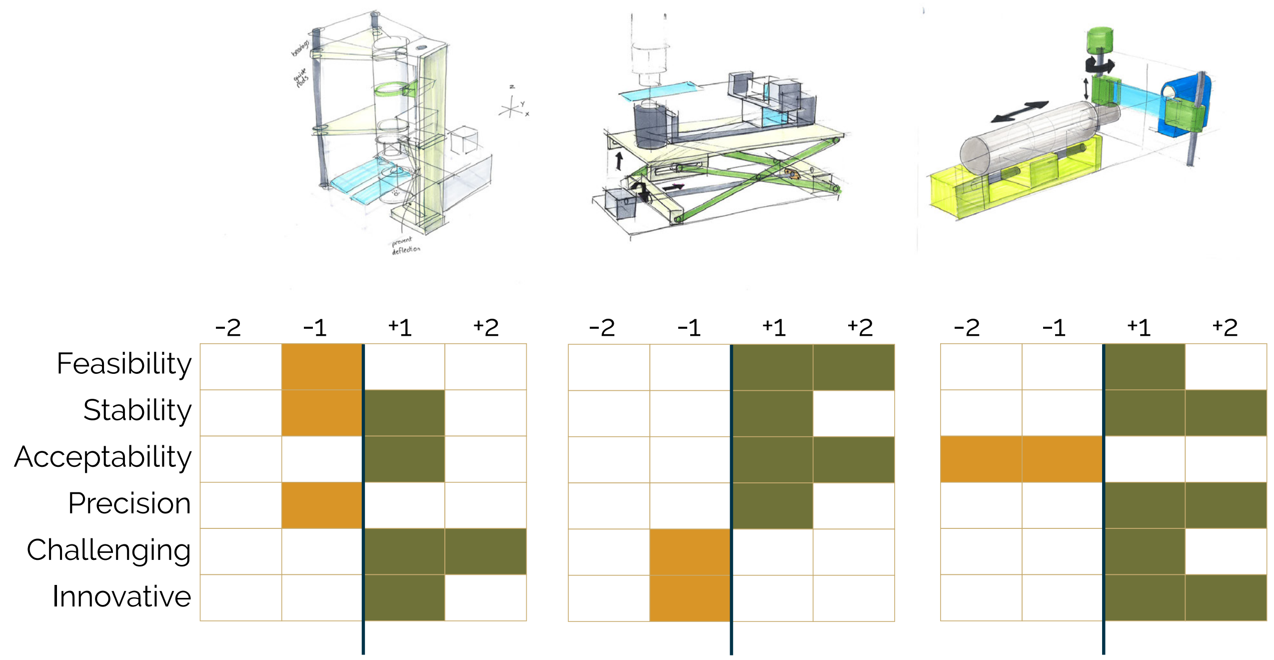


Figure 56. Method choosing concept

List of Requirements 3

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm

2 The glass slide should maintain position of a urine filter

2 The sample should always remain horizontally flat to prevent the filter from falling off

3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide

4 The device must allow for a change of glass slide

5 All materials used for the device must sustain their physical properties after being cleaned by alcohol

6 The device must allow for the use of a 4X microscope objective

7 The device must adequately illuminate the sample

8 The device must allow for the use and change of a microscope objective

9.1 Either the camera sensor or the sample must move in the focus direction, z-axis

9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis

9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis

9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis

9.5 Either the illumination or the sample must move in the short sample direction, x-axis

9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis

9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis

9.8 Either the illumination or the sample must move in the long sample direction, x-axis

9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis

10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm

11 The device must allow for levelling of the sample bed

12 The device must allow for the use of a Jetson Nano Developer board

13 The device must allow for the use of a Jetson Nano Camera

14 The device must be reliable

15 The device must operate in climate temperatures of at least 50 degrees celcius

16 The device must provide stability to the integrated systems

17 The device must house specific electronic components

18 The device must have a robust appearance

19 The device must enable automated x, y and z movements

20 The device must facilitate a z-movement step size of 5um

21 The weight of a component should be close to the point of applied forces

Unchanged | *Added* | *Adapted or removed requirement*

PDCA-3

Z-triangle

Plan

Create a design that directly improves the optical train and z-movement of the Schistoscope 4. The design is driven by a stepper motor and lead screw and guided by rods, as explained in chapter PDCA-2, concept 1. Furthermore. it must include features to contain or mount all components needed for the optical train, for example the camera and microscope objective.

Challenges

Challenge 1: Improve the stability and fixation of the camera

Challenge 3: Ensure consistent field of view

Challenge 5: Provide stability of all systems inside the device

Do

3D-printing is the production method of preference, as explained in chapter Envisioned Schistoscope. Therefore, the design solution created uses 3D-printing as main production method. The solution created in this PDCA-cycle, is a 3D-printed triangular shape, guided by three rods and driven by a stepper motor with lead screw.

The 3D-printed component is called the z-triangle. Attached to the z-triangle is a lead screw nut, which encircles a lead screw. This leadscrew is connected to a stepper motor, which is mounted on a top surface. This top surface mount three guide rods, by which the z-triangle is guided. The guide rods are additionally mounted at a base surface. When powering the stepper motor, the lead screw will rotate and consequently the screw nut. However, since the nut is mounted inside the z-triangle, and the z-triangle is restricted to rotate on six point due to the three guide rods, the z-triangle will not rotate but move linear up or down (figures 57and 58)

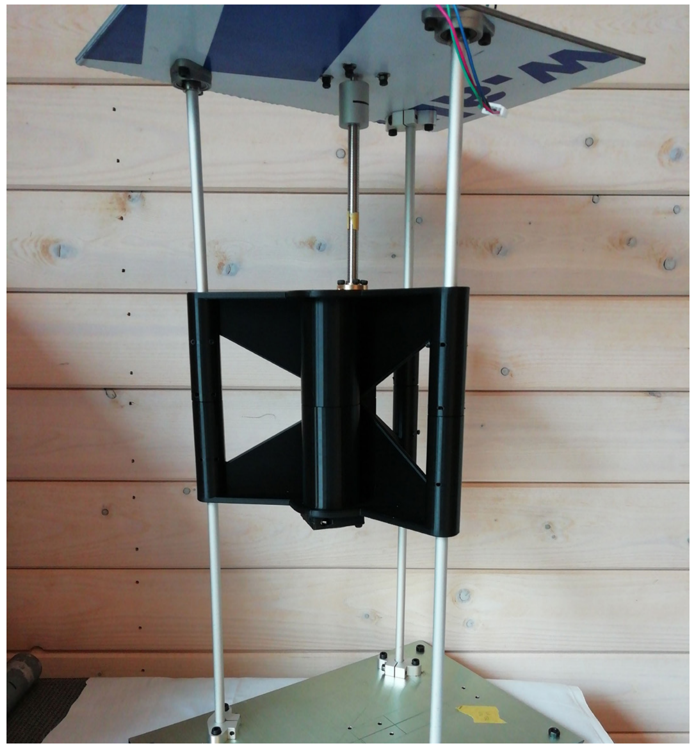


Figure 57. Z-trianlge 1

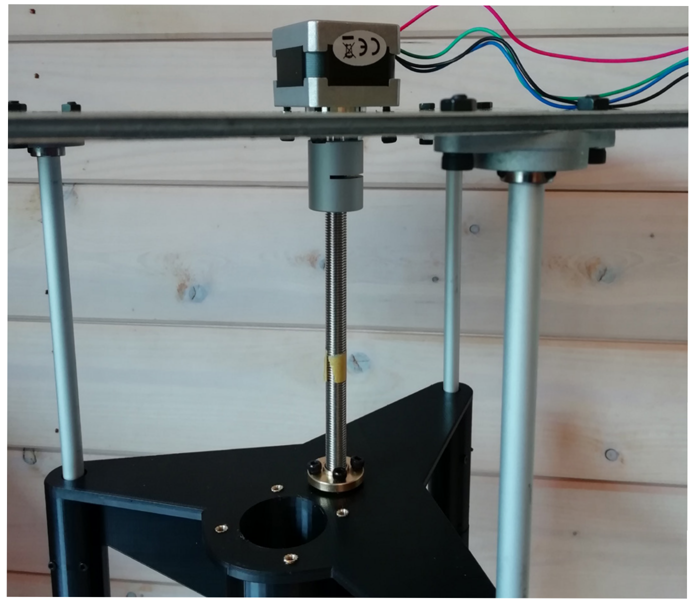


Figure 58. Topview Z-trianlge 1

On top of the z-triangle, a camera can be mounted with 4 screws. The screws will lock into thread inserts, small copper tubes with internal threading that can be melted into 3D-printed parts. At the bottom of the z-triangle, a 3D-printed ring-mount is connected to the z-triangle. The mount clamps an RMS thread ring, a copper ring with internal RMS thread, which allows for the microscope objective, with external RMS thread to be locked into the ring, onto the z-triangle.

The design is made of two parts that are connected in four cylinders. In the three outer cylinders, linear bearings are inserted which glide along the guide rods, guiding the z-triangle along the z-direction. The design is focused on making a strong and rigid component, which can move in no other direction than up or down. Triangular beams prevent the corners from deflecting.

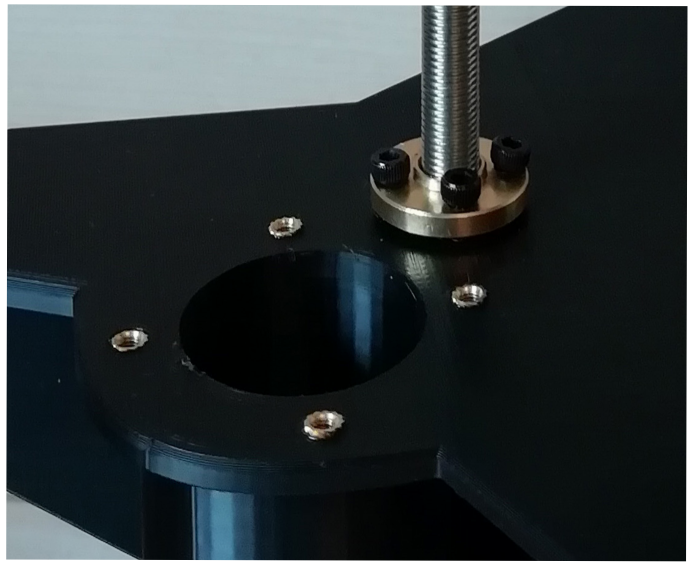


Figure 59. Close-up top Z-trianlge 1

Check

Connecting the stepper motor on the control software and testing this design provided promising results. The linear z-movement was straight, accurate and stable. The required step size of req 20 is provided and there is enough space for a sample movement system underneath the z-triangle and in-between the guide rods. Some small improvements must include a longer linear z-direction travel distance, and the camera sensor should be aligned with the glass slide.

Act

Improve the current design with the new set of requirements. Furthermore, the design can be decreased in size. This will improve printing time and portability of the device.

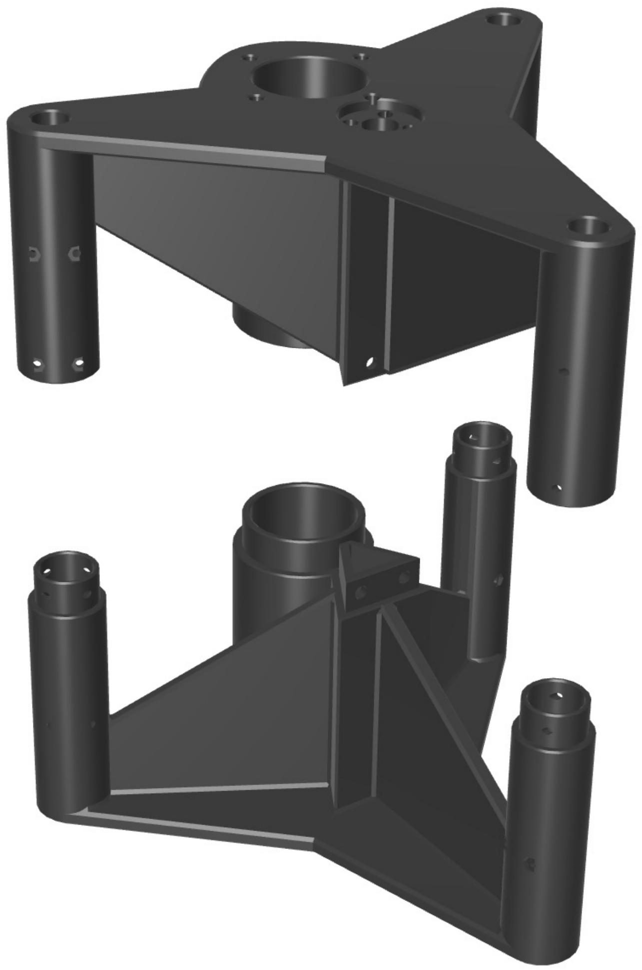


Figure 61 Parts of Z-trianlge 1

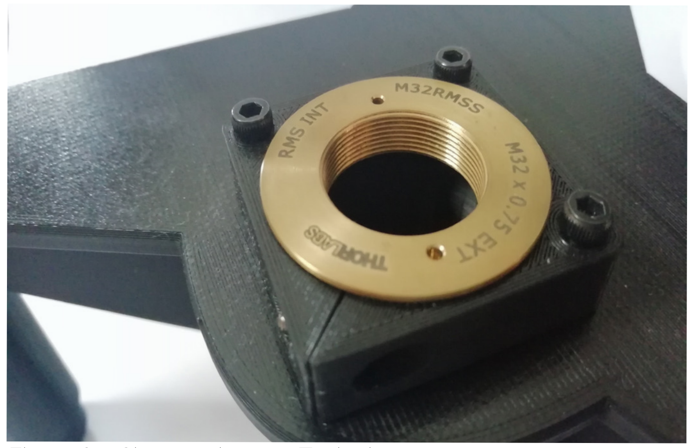


Figure 60. Close-up bottom Z-trianlge 1

List of Requirements 4

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm
2 The sample should always remain horizontally flat to prevent the filter from falling off
3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide
4 The device must allow for a change of glass slide
5 All materials used for the device must sustain their physical properties after being cleaned by alcohol
6 The device must allow for the use of a 4X microscope objective
7 The device must adequately illuminate the sample
8 The device must allow for the use and change of a microscope objective
9.1 Either the camera sensor or the sample must move in the focus direction, z-axis
9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis
9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis
9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis
9.5 Either the illumination or the sample must move in the short sample direction, x-axis
9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis
9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis
9.8 Either the illumination or the sample must move in the long sample direction, x-axis
9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis
10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm
11 The device must allow for levelling of the sample bed
12 The device must allow for the use of a Jetson Nano Developer board
13 The device must allow for the use of a Jetson Nano Camera
14 The device must be reliable
14 The camera sensor should be aligned with the glass slide in x- and y-direction
15 The device must operate in climate temperatures of at least 50 degrees celcius
16 The device must provide stability to the integrated systems
17 The device must house specific electronic components
18 The device must have a robust appearance
19 The device must enable automated x, y and z movements
20 The device must facilitate a z-movement step size of 5um
21 The weight of a component should be close to the point of applied forces
22 The total number of components should be as low as possible
23 The design must allow for a travel distance of minimal 20mm
24 The device must allow for the entire sample to be scanned
25 The system should not be overconstrained

Unchanged | *Added* | *Adapted or removed requirement*

PDCA-4

Configuration of triangle

Plan

This cycle aims for a better alignment of the z-triangle towards the sample moving system. The z-triangles size must be reduced and allow for the camera to be aligned with the sample. This cycle also addresses the configuration between several systems, to find an optimal configuration, with regards to volume, stability and reliability.

By looking at the configuration of the moving systems, the optimal configuration can be found. The goal is to optimise in terms of stability, size and reliability of the configuration.

An advantage of finding a smaller sized solution is the reduced printing time of the z-triangle. Decreasing the device with 10% decreases printing time. Furthermore, it can decrease the total volume of the device, which is preferable for usability reasons and for transportation during the field test in Nigeria.

Challenges

Challenge 1: Improve the stability and fixation of the camera

Challenge 3: Ensure consistent field of view

Challenge 5: Provide stability of all systems inside the device

Do

By using cardboard substitutes, several configurations were made. A first insight was that the guide rods of the z-triangle would interfere with the sample movement system. One way to solve that, allowing them to interfere, is by putting the rod on a supported ledge above the sample movement system. By doing so, more configurations are possible, helping to achieve the smaller sizes. However, this could limit the reliability and the stability of the design.

Another insight was the way the sample is inserted. The Schistoscope 4 places the sample into a slot over the long side of the slide. However, in standard microscopy, the sample is put on a table surface and slid underneath clips, over the short side. This introduced the idea that the sample could be inserted into a slot over the short side. This exploration is further explained in PDCA-cycle 11. The results of that cycle are considered in choosing the optimal configuration.

Three configurations are ranked on their influence on four factors. The first factors are of higher importance than design aesthetic because the field test requires higher values for functionality and usability than aesthetics.

1. Small size
2. Stable with no ledge
3. User-friendly sample insertion
4. Design aesthetic

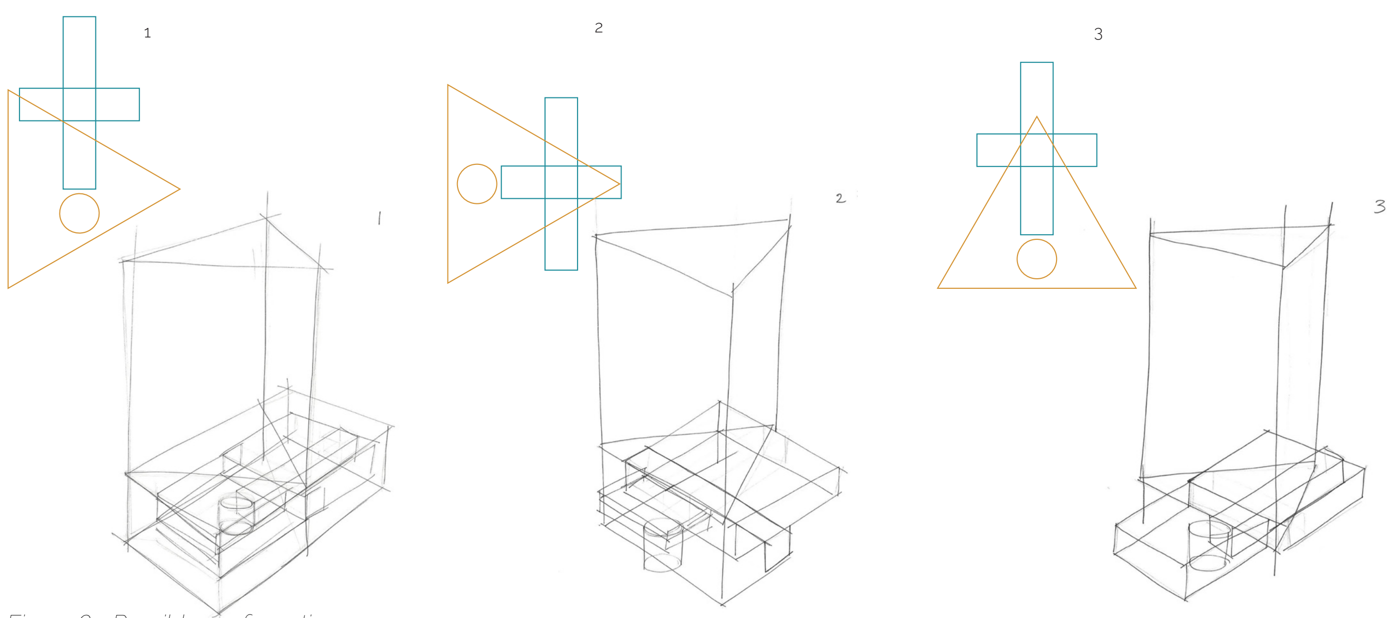


Figure 62. Possible configurations

After prioritising the factors, and rating the configurations on these factors, the decision was made to continue with the configuration that would provide the smallest, most stable solution, with the conventional way to insert the sample. This design was mainly based on user experience, see PDCA-cycle 11.

For the linear bearings, the Igus Drylin Bearings are used. These bearings are lightweight, easy to implement and lubricant-free. Inside each outer cylinder, at top and bottom, a bearing is placed. The bearing must guide the z-triangle along the rods with as little friction as possible. The bearings are hold in place with a nut and bolt, to prevent the bearing from moving away.

The new configuration was produced into an improved 3D-model, a smaller z-triangle with the camera aligned to the sample.

Figure 63. Bearing inside Z-trianlge

Figure 64. Z-trianlge 1 and 2

Check

After printing, building and setting up the new design, some issues were identified. Even though the previous z-triangle would move linearly along the z-axis, effortlessly along the guide rods, the new z-triangle got stuck. Too much friction between the bearings and the guide rods prevented the model from moving. After analysing the set-up, the cause was found in the 3D-printed model. The cylinders appear to be crooked. During the print, the cylinders were deflected, causing the bearings to be misaligned relative to the other bearing in the cylinder. Because of that, a thing called Stick-Slip Phenomenon occurred [18].

In conclusion, the design was over-constrained. In the attempt to create the most rigid solution, the design found too many tolerances. All these tolerances build on each other, each tolerance requires to be in synergy with the others. When those tolerances are out of synergy, at some point, the system becomes unable to move due to the level of friction. Most commercially available 3D-printers deliver limited quality. Combining the limited quality of the available 3D-printers with a design that requires.

Each object has 6 degrees of freedom, and each degree of freedom must be constrained or allowed to be free according to the functional requirements of the system [19]. Adding constraints, can limit the degrees of freedom of your design. Each bearing adds 4 constraints, and a lead screw also adds 4 constraints. Multiple bearings can constrain the same degrees, creating over-constraints, making the system over-defined. The z-movement requires 1 degree of freedom, along the Z-axis. The current design has 14 over constraints, to many bearings adding no additional constraints.

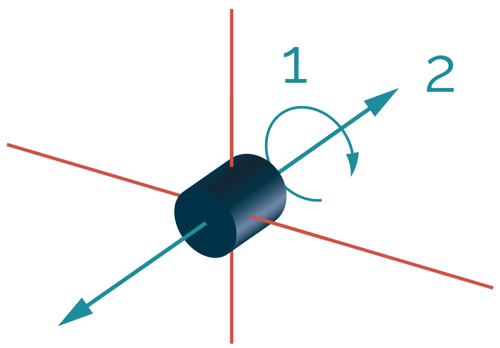


Figure 65. Degrees of freadom of bearing

Act

The next PDCA-cycle requires to take a couple steps back. The cycle must aim to create a design with less components and fewer over-constraints. Furthermore, the awareness of the dynamic aspect of this project is created. Because of parallel research projects that have implications to this graduation project, aspects, facts and requirements can change over the course of time. Therefore, a new requirement is set, that requires the device to be adaptable. The device must be able to adapt quickly to changes in hardware, software or requirements. For example, at the start of the project, the device was set to use a Jetson Nano camera. However, the software and AI has been further developed and now require the use of a Raspberry Pi camera instead of the Jetson Nano Camera.

Furthermore, the project must diverge from the use of 3D-printing as one of the main production methods. This device requires microscopic precision, a precision most commercially available 3D-printers cannot deliver. 3D-printing is not considered a suitable method, especially when designing for a scalable production. Going forwards, 3D-printing is predominantly considered specialised for small parts that do not require high precision.

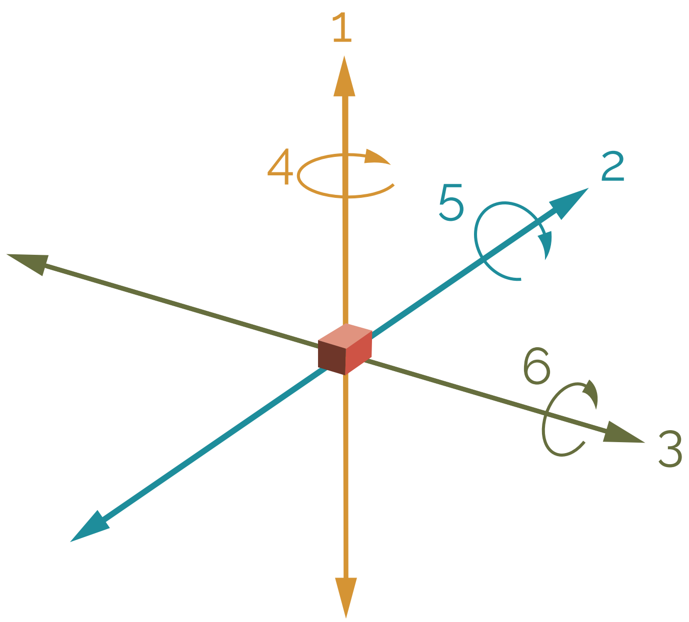


Figure 66. Degrees of freedom of an object

List of Requirements 5

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm
2 The sample should always remain horizontally flat to prevent the filter from falling off
3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide
4 The device must allow for a change of glass slide
5 All materials used for the device must sustain their physical properties after being cleaned by alcohol
6 The device must allow for the use of a 4X microscope objective
7 The device must adequately illuminate the sample
8 The device must allow for the use and change of a microscope objective
9.1 Either the camera sensor or the sample must move in the focus direction, z-axis
9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis
9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis
9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis
9.5 Either the illumination or the sample must move in the short sample direction, x-axis
9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis
9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis
9.8 Either the illumination or the sample must move in the long sample direction, x-axis
9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis
10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm
11 The device must allow for levelling of the sample bed
12 The device must allow for the use of a Jetson Nano Developer board
13.1 The device must allow for the use of a Jetson Nano Camera
13.2 The device must allow for the use of a Raspberry Pi Camera
14 The camera sensor should be aligned with the glass slide in x- and y-direction
15 The device must operate in climate temperatures of at least 50 degrees celcius
16 The device must provide stability to the integrated systems
17 The device must house specific electronic components
18 The device must have a robust appearance
19 The device must enable automated x, y and z movements
20 The device must facilitate a z-movement step size of 5um
21 The weight of a component should be close to the point of applied forces
22 The total number of components should be as low as possible
23 The design must allow for a travel distance of minimal 20mm
24 The device must allow for the entire sample to be scanned
25 The system should not be overconstrained
26 The set-up must be adaptable to changes in hardware

Unchanged | *Added* | *Adapted or removed requirement*

PDCA-5

Degrees of freedom

Plan

This cycle aims to take the insights gathered in the previous cycles into a new design proposal. It is important to consider the constraints needed for z-movement and make a design that fits these requirements. Therefore, this cycle must use take the considerations and translate them into a feasible design.

Challenges

Challenge 1: Improve the stability and fixation of the camera

Challenge 3: Ensure consistent field of view

Challenge 5: Provide stability of all systems inside the device

Do

As described in cycle 4, each object has 6 degrees of freedom. Adding constraints limits the degrees of freedom of your design. One bearing will add 4 constraints, 2 axile constraints and the rotational constraints, leaving the object with 2 degrees of freedom.

With these considerations in mind, the following design was created. Three cylinders in a row, connection a top and bottom surface. The largest cylinder on one side will act as extension tube between camera and objective to ensure the fixed distance between those components. The middle cylinder would mount a lead screw and leadscrew nut. The last cylinder would house 1 single Igus Drylin bearing, to prevent the design from tilting.

While creating this design, the resemblance with a motorised slider became clear. These sliders contain the needed leadscrew, guide rail and stepper motor that is required in a reliable guiding system. This motorised slider could be attached to a stable construction such as an aluminium profile frame, like many 3D-printers, CNC-machines and other motorised equipment use. The use of aluminium profiles was the result of a brainstorm session during this cycle. More about this session in Appendix E.

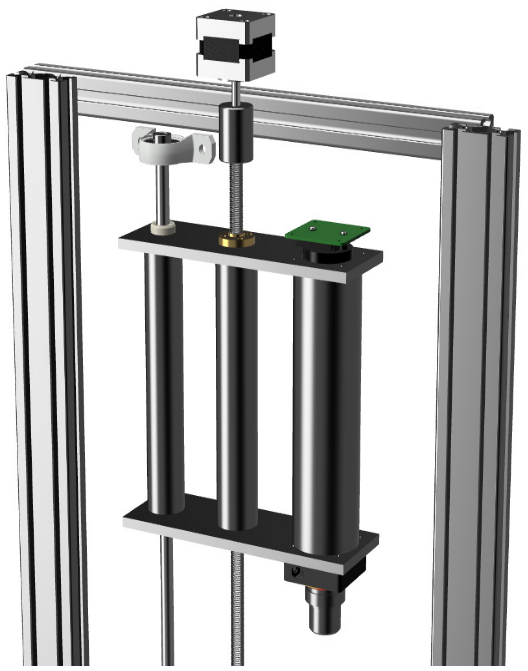


Figure 67: Model of linear guide system for Schistoscope

Figure 68 Guide Rail Linear Actuator 1605 from DennisDeal

Check

Discussion with the research group concluded with the decision of using a motorised linear guide system, as shown in figure 69, attached to an aluminium profile.

A quick test set-up was produced to do a quick proof of concept test. The way the aluminium profiles are constructed in figure 69 and 70 proof not to be ideal. The profiles were too long, which created a disbalance that affected the stability of the set-up. However, the stiffness and adaptability of the profiles satisfied the requirements. More about the use of aluminium profiles in cycle 11.

Act

A next cycle about the use of motorised sliders for both x, y and z-movement should be executed. Other cycles addressing the aluminium profiles and the use of a tube and clamp to attach to these sliders must follow if the direction of motorised sliders proves feasible.

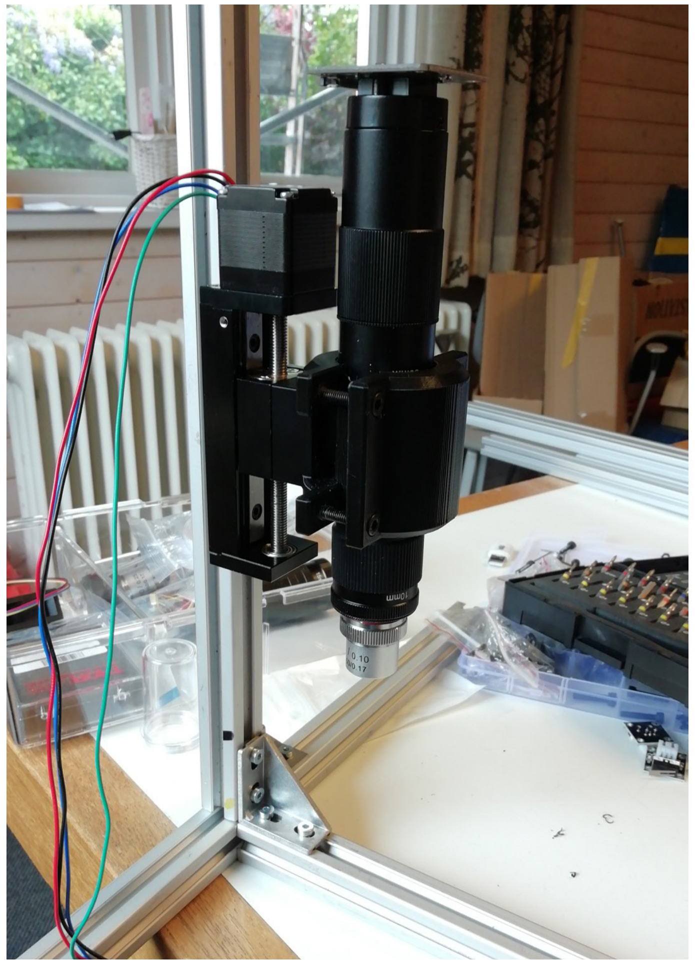


Figure 69 Initital set-up automated linear rail

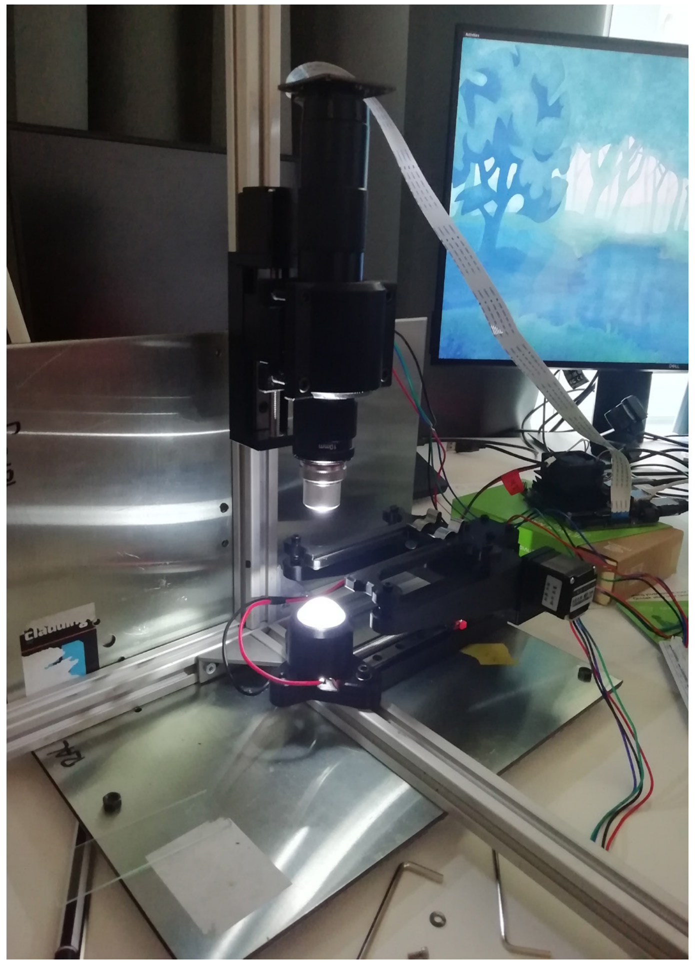


Figure 70 Initital test automated linear rail

List of Requirements 6

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm

2 The sample should always remain horizontally flat to prevent the filter from falling off

3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide

4 The device must allow for a change of glass slide

5 All materials used for the device must sustain their physical properties after being cleaned by alcohol

6 The device must allow for the use of a 4X microscope objective

7 The device must adequately illuminate the sample

8 The device must allow for the use and change of a microscope objective

9.1 Either the camera sensor or the sample must move in the focus direction, z-axis

9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis

9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis

9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis

9.5 Either the illumination or the sample must move in the short sample direction, x-axis

9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis

9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis

9.8 Either the illumination or the sample must move in the long sample direction, x-axis

9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis

10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm

11 The device must allow for levelling of the sample bed

12 The device must allow for the use of a Jetson Nano Developer board

13.1 The device must allow for the use of a Jetson Nano Camera

13.2 The device must allow for the use of a Raspberry Pi Camera

14.1 The camera sensor should be aligned with the glass slide in x- and y-direction

14.2 The optical set-up mustensure alignment of camera sensor, slide and illumination

14.3 The device must ensure reliable movement

14.4 The device must ensure alignment over time

15 The device must operate in climate temperatures of at least 50 degrees celcius

16 The device must provide stability to the integrated systems

17 The device must house specific electronic components

18 The device must have a robust appearance

19 The device must enable automated x, y and z movements

20 The device must facilitate a z-movement step size of 5um

21 The weight of a component should be close to the point of applied forces

22 The total number of components should be as low as possible

23 The design must allow for a travel distance of minimal 20mm

24 The device must allow for the entire sample to be scanned

25 The system should not be overconstrained

25 All axile movement should only have 1 degree of freedom, in the linear directiona

26 The set-up must be adaptable to changes in hardware

27 The device should facilitate a x- and y-step size of at least 1mm

28 The device should be reproducable

Unchanged

Added

Adapted or removed requirement

PDCA-6

Sliders

Plan

The Schistoscope 4 uses 'home-made' motorised linear guiding systems. Commonly known as sliders. These sliders are powered by a stepper motor, which rotates a leadscrew connected to a leadscrew nut, which is captured inside a block. This block is fixated onto a glide block that glides frictionless over the guide rail underneath. Linear guiding systems are commonly used in automated assembly, production lines, medical technology and film industry [2].

The home-made sliders are large and lack the required precision in movement. These sliders consist of metal and 3D-printed parts. The tolerances due to the 3D-printing quality create misalignment of the metal elements, which creates deviations from the intended movements. The goal for this cycle is to find a solution that is less bulky, more reliable and precise and scalable to future designs

Challenges

Challenge 2: Allow for different Field of View of sample

Challenge 3: Ensure consistent field of view

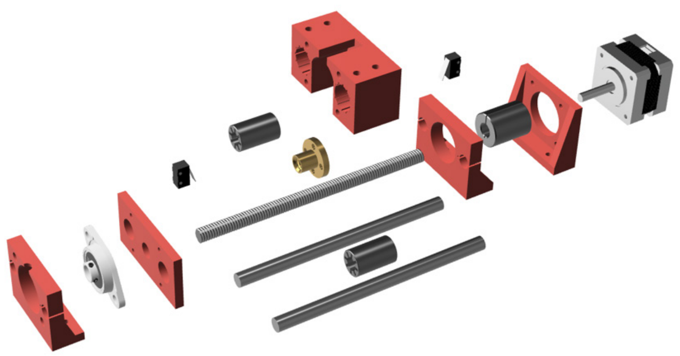


Figure 71. Exploded view slider Schistoscope 4

Do

As mentioned before in cycle 4, 3D-printing is predominantly specialised for small parts that do not require high precision. This linear guiding system exactly requires high precision, and therefore 3D-printing is not considered a suitable method, especially when designing for a scalable production. The goal is a reliable system with microscopic precision.

During the PDCA-5 cycle, the use of aluminium profiles acting as guide rail was considered. When looking back at the Schistoscope 4, the use of home-made sliders, the possibility of off-the-shelf sliders surfaced. These sliders contain the needed leadscrew, guide rail and stepper motor that is required in a reliable guiding system. Keeping in mind that the device must be adaptable, splitting the supporting system from the moving system allows for this adaptability. Either changing the slider or the supporting system, the other system is not influenced, or does not require big changes.

These off-the-shelf sliders are reliable; they are made with an acceptable production precision. They are significantly smaller and more implementable than home-made sliders like in the Schistoscope 4. They come with NEMA 11 stepper motors, which are better suitable motor then NEMA 14, used in the Schistoscope 4. Another advantage of the off-the-shelf slider is its price. the complete off-the-shelf slider can be acquired for approximately 33 euros. while for the Schistoscope 4 slider acquired for at least 24 euros plus additional printing materials and production time (see Appendix B).

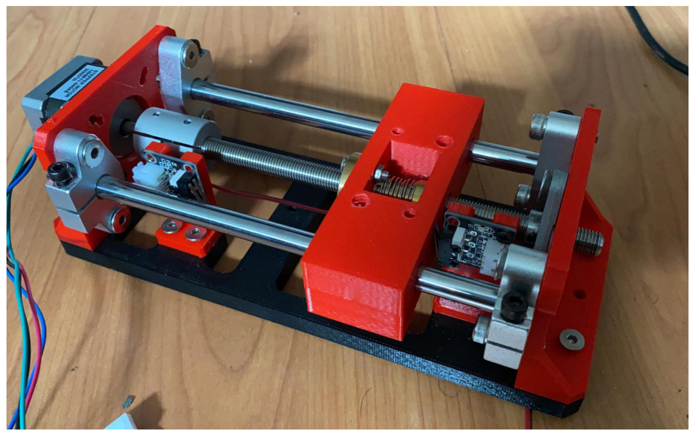


Figure 72. Slider Schistoscope 4

Check

The solution is affordable, scalable, reliable, and adaptable. However, there are some concerns about the quality and reliability of ordering from Chinese suppliers, for example AliExpress. The mutual difference in quality between components from China can differ a lot. Quality is not a guarantee when ordering from China, even within a large order from the same supplier.

Act

In the next cycles, solutions must be created to agree with the use of motorised sliders. The sliders are meeting the system requirement, are affordable and reliable. They allow for easy assembly and changes in other design. Therefore, they are a convenient solution, and the next designs should match with the sliders.

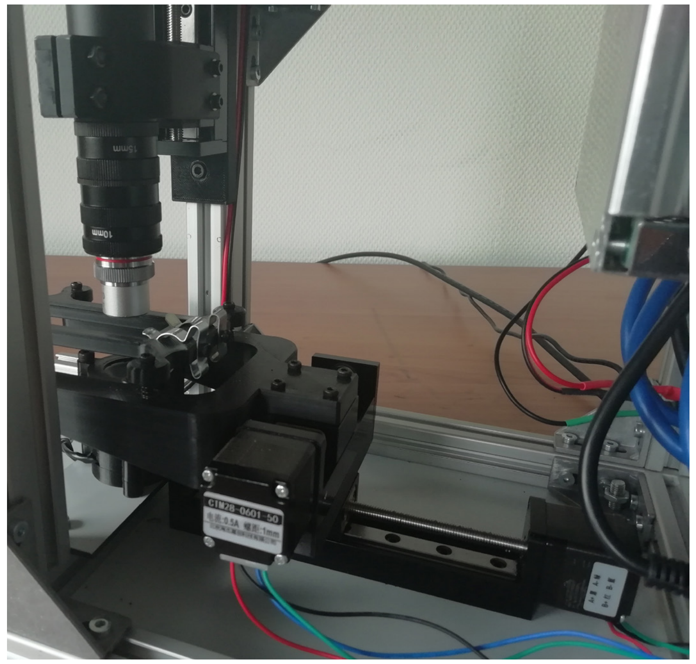


Figure 73. Sliders included in Schistoscope 5

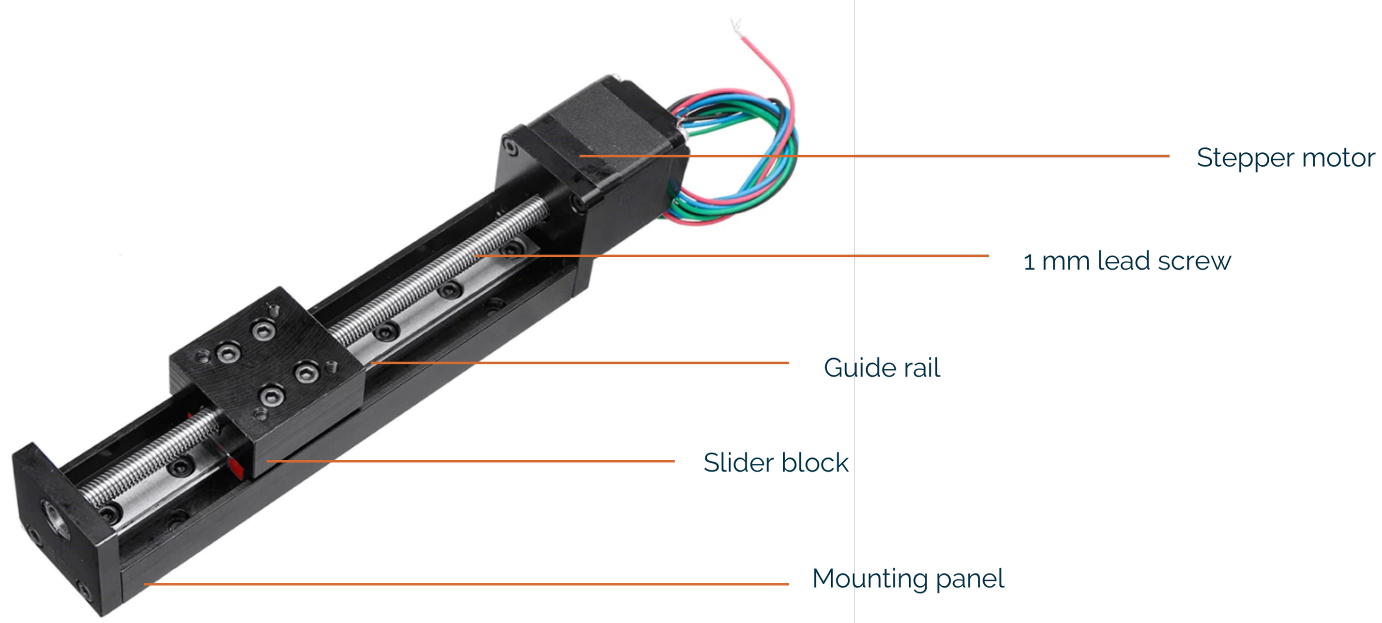


Figure 74. Slider Schistoscope 5

List of Requirements 7

1	The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm
2	The sample should always remain horizontally flat to prevent the filter from falling off
3	The device must be able to scan the entire 13 mm filter placed at any position of a glass slide
4	The device must allow for a change of glass slide
5	All materials used for the device must sustain their physical properties after being cleaned by alcohol
6	The device must allow for the use of a 4X microscope objective
7	The device must adequately illuminate the sample
8	The device must allow for the use and change of a microscope objective
9.1	Either the camera sensor or the sample must move in the focus direction, z-axis
9.2	The illumination and the sample must remain at the same distance in the focus direction, z-axis
9.3	The illumination and the camera sensor have no relative movement in the focus direction, z-axis
9.4	Either the camera sensor or the sample must move in the short sample direction, x-axis
9.5	Either the illumination or the sample must move in the short sample direction, x-axis
9.6	The illumination and the camera sensor must move equally in the short sample direction, x-axis
9.7	Either the camera sensor or the sample must move in the long sample direction, y-axis
9.8	Either the illumination or the sample must move in the long sample direction, x-axis
9.9	The illumination and the camera sensor must move equally in the long sample direction, x-axis
10	The distance between the camera sensor and the bottom of the objective thread must be 160 mm
11	The device must allow for levelling of the sample bed
12	The device must allow for the use of a Jetson Nano Developer board
13.1	The device must allow for the use of a Jetson Nano Camera
13.2	The device must allow for the use of a Raspberry Pi Camera
14.1	The camera sensor should be aligned with the glass slide in x- and y-direction
14.2	The optical set-up mustensure alignment of camera sensor, slide and illumination
14.3	The device must ensure reliable movement
14.4	The device must ensure alignment over time
15	The device must operate in climate temperatures of at least 50 degrees celcius
16	The device must provide stability to the integrated systems
17.1	*The device must house specific electronic components*
17.2	*The devicce must use a Switch Mode Power Supply to adapt voltagesA*
18	The device must have a robust appearance
19	The device must enable automated x, y and z movements
20	The device must facilitate a z-movement step size of 5um
21	The weight of a component should be close to the point of applied forces
22	The total number of components should be as low as possible
23	The design must allow for a travel distance of minimal 20mm
24	The device must allow for the entire sample to be scanned
25	All axile movement should only have 1 degree of freedom, in the linear directiona
26	The set-up must be adaptable to changes in hardware
27	*The device should facilitate a x- and y-step size of at least 1mm*
27	*The device should facilitate a motorised x- and y-step size of at least 1mm*
28	The device should be reproducable

Unchanged

Added

Adapted or removed requirement

PDCA-7

Tube

Plan

An extension between objective and camera sensor is needed for optimal images. The total distance from the bottom of the objective's thread to the surface of the camera board should be approximately 160mm [8].

In the Schistoscope 4 an extension tube is 3D-printed. It existed of 4 different parts and connects the camera to the tube by using magnets. One side of the tube is mounted to the z-movement. Chapter Schistoscope 4.0 explains the issues that occur when implementing this tube design.

Challenges

Challenge 1: Improve the stability and fixation of the camera.

Challenge 3: Ensure consistent field of view

Do

There is no off-the-shelve component that meets the requirements with the specific thread-mount as well as the required length. As concluded earlier in chapter 4, this project considers 3D-printing mainly as a production tool for small and components with few details, after several failed explorations to do otherwise. There are still other methods to produce components. There are special threading tools to create specific thread dimensions. The tools required for standard thread sizes are commonly available and reasonably easy to operate. However, the requirements demand very specific, special thread sizes (RMS and C-mount). The tools to create these thread sizes are expensive (€€). Besides the price, producing these thread sizes are more difficult and require expertise to create.
Even though there are no off-the-shelve components that meet the exact requirements, there are components that available that are considered adequate alternatives. For example, combining commonly available C-mount extension tubes of different sizes, can create the required length. To create the required thread-mount, one adapter ring from C-mount to RMS can be screwed into the extension tube combination. Together these components create a set-up that meet the requirements with the specific thread-mount as well as the required length, see figure 76.

Check

One advantage of this solution is the adaptability. Even though the current requirement is set for a length of 160mm. The project might require a different length at a different point in the project. This solution allows for easy adaptation, adding or removing parts of the tube to get to the required length. Furthermore, any camera with C-mount thread can be screwed on top of the tube. Other cameras are also easily attached, with the use of one simple adapter ring, which are commonly available [21].

Act

A next cycle should address the method of attaching the tube to the slider. Additionally, more research must be executed on the production of a tube with the preferred dimensions. Even though a tube of 160mm is not available, companies take custom orders and will add your custom product to their assortment, if the demand is large enough [3].

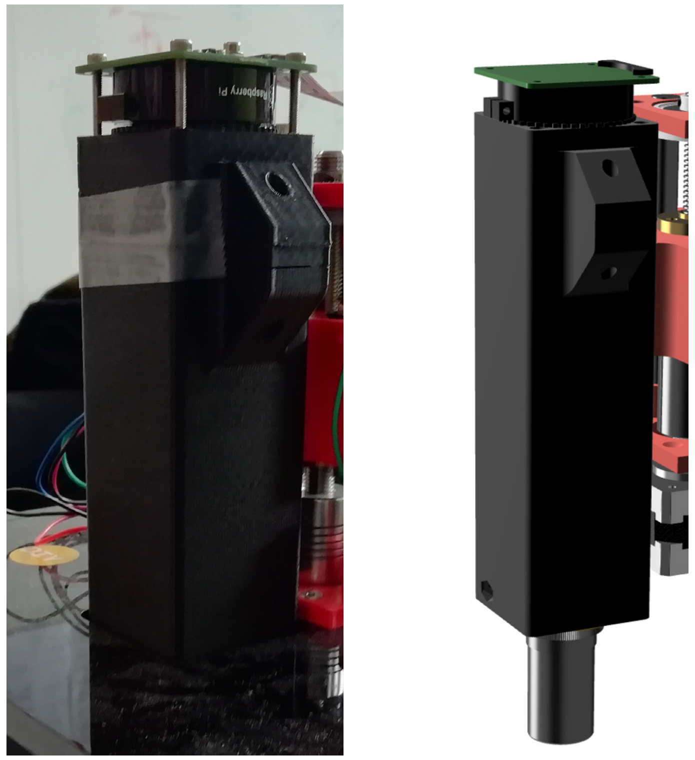


Figure 75 Tube Schistoscope 4

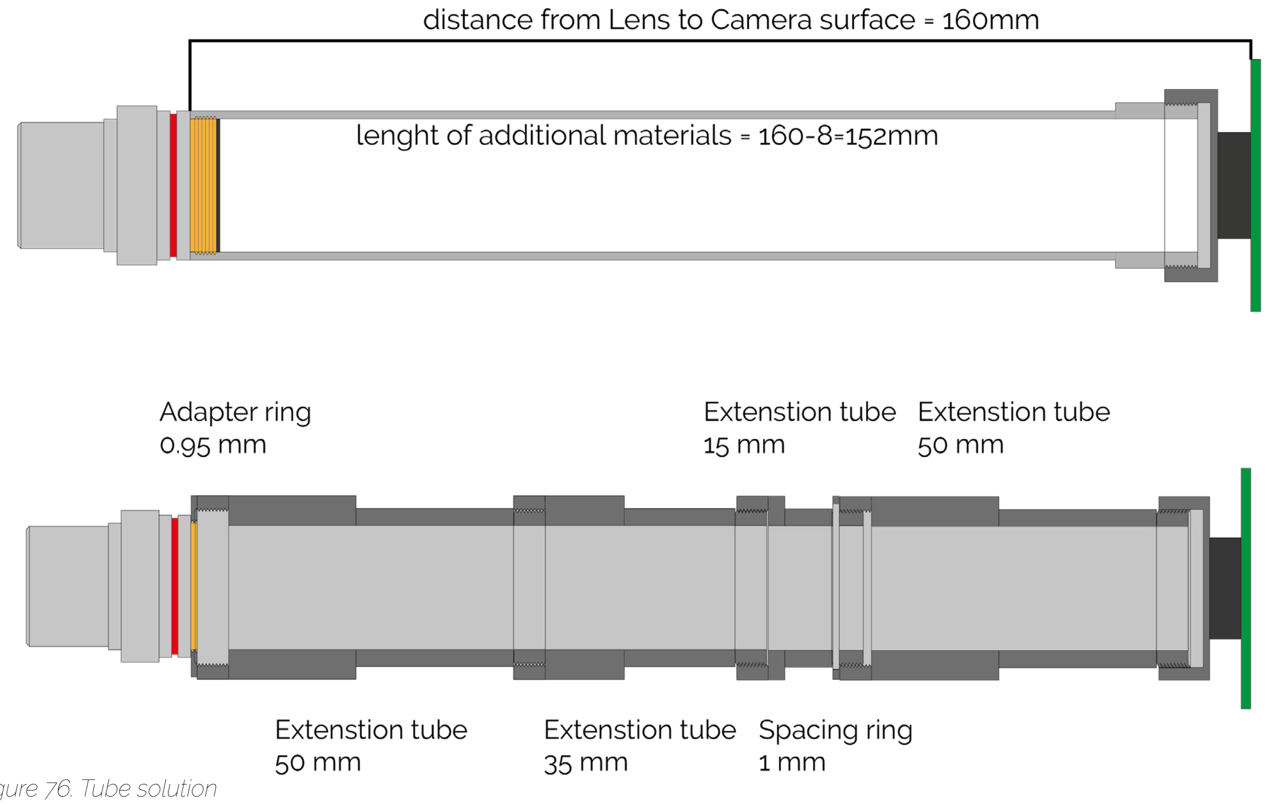


Figure 76. Tube solution

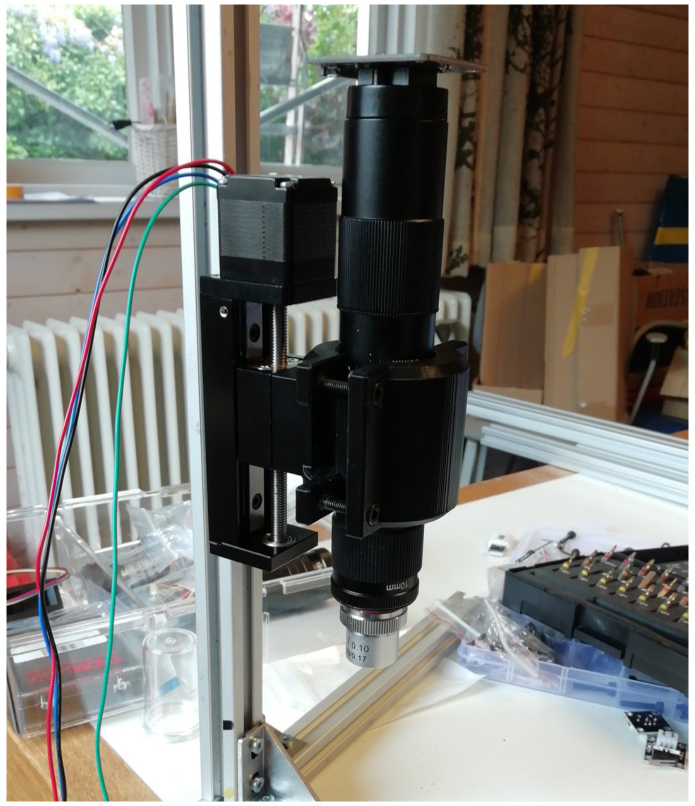


Figure 77. Initial tube set-up

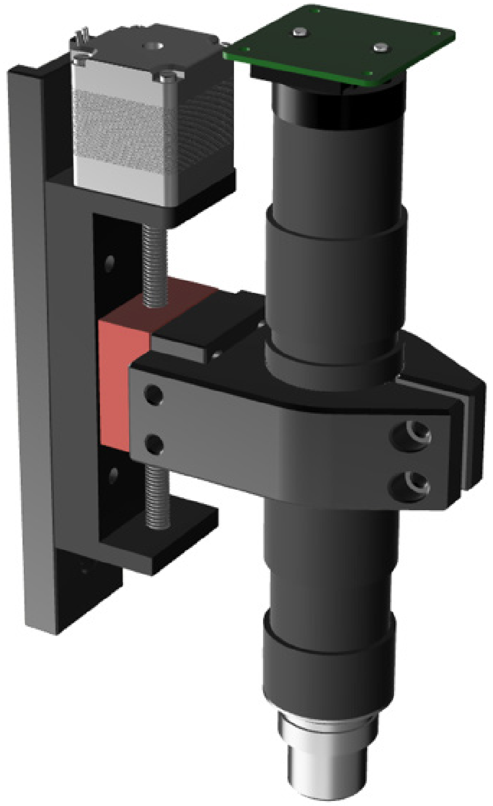


Figure 78. Model of tube set-up

List of Requirements 8

1	The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm
2	The sample should always remain horizontally flat to prevent the filter from falling off
3	The device must be able to scan the entire 13 mm filter placed at any position of a glass slide
4	The device must allow for a change of glass slide
5	All materials used for the device must sustain their physical properties after being cleaned by alcohol
6	The device must allow for the use of a 4X microscope objective
7	The device must adequately illuminate the sample
8	The device must allow for the use and change of a microscope objective
9.1	Either the camera sensor or the sample must move in the focus direction, z-axis
9.2	The illumination and the sample must remain at the same distance in the focus direction, z-axis
9.3	The illumination and the camera sensor have no relative movement in the focus direction, z-axis
9.4	Either the camera sensor or the sample must move in the short sample direction, x-axis
9.5	Either the illumination or the sample must move in the short sample direction, x-axis
9.6	The illumination and the camera sensor must move equally in the short sample direction, x-axis
9.7	Either the camera sensor or the sample must move in the long sample direction, y-axis
9.8	Either the illumination or the sample must move in the long sample direction, x-axis
9.9	The illumination and the camera sensor must move equally in the long sample direction, x-axis
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11	The device must allow for levelling of the sample bed
12	The device must allow for the use of a Jetson Nano Developer board
13.1	The device must allow for the use of a Jetson Nano Camera
13.2	The device must allow for the use of a Raspberry Pi Camera
14.1	The camera sensor should be aligned with the glass slide in x- and y-direction
14.2	The optical set-up mustensure alignment of camera sensor, slide and illumination
14.3	The device must ensure reliable movement
14.4	*The device must ensure alignment over time*
14.4	*Components used to align systems should remain physically reliable over time*
15	The device must operate in climate temperatures of at least 50 degrees celcius
16	The device must provide stability to the integrated systems
17.1	The device must house specific electronic components
17.2	The devicce must use a Switch Mode Power Supply to adapt voltagesA
18	The device must have a robust appearance
19	The device must enable automated x, y and z movements
20	The device must facilitate a z-movement step size of 5um
21	The weight of a component should be close to the point of applied forces
22	The total number of components should be as low as possible
23	The design must allow for a travel distance of minimal 20mm
24	The device must allow for the entire sample to be scanned
25	All axile movement should only have 1 degree of freedom, in the linear directiona
26	The set-up must be adaptable to changes in hardware
27	The device should facilitate a motorised x- and y-step size of at least 1mm
28	The device should be reproducable

Unchanged — *Added* — *Adapted or removed requirement*

PDCA-8

Clamp

Plan

For the optical system to produce reliable images, the set-up must be aligned. The tube must be horizontal and must not be able to rotate since that would affect the alignment of the camera sensor and the glass slide. Besides being horizontally aligned, the tube must not tilt away from the z-axis. This would affect the trajectory of the light beam. This cycle focuses on a solution to attach the tube to the slider, in a way that the alignments are ensured, even after a long period of use.

Challenges

Challenge 1: Improve the stability and fixation of the camera.

Challenge 3: Ensure consistent field of view

Do

During this cycle, several clamps were designed, printed and tested. The factors considered during these tests were:

- strenght,
- printing time,
- ease of implementation,
- contribution to alignment.

One of the difficulties in the design of this clamp it the attachment to the slider. The slider block has 4 threaded holes at the top surface, to allow for attachments. The clamp can be mounted directly on these holes, as applied in models 1-5, figure 79. However, the research team requested the possibility of removing the tube, without clamp, while not removing the slider. That is no difficult request, however, the research team required the detached components to be placed back in the exact same position, without extra action for the user.

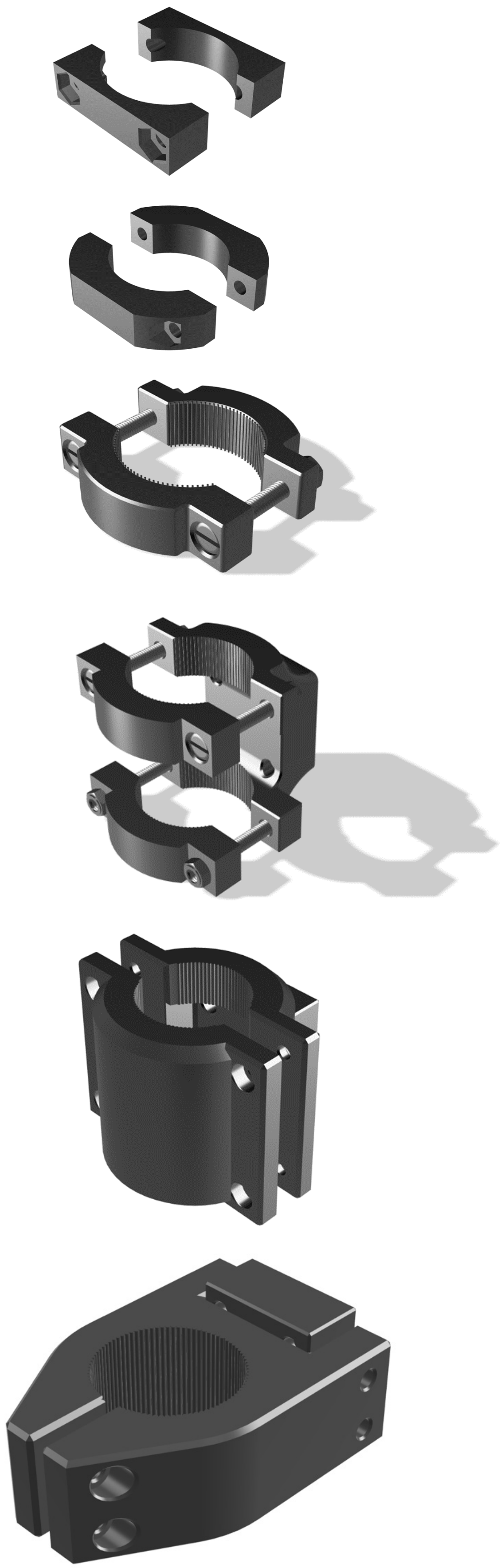


Figure 79. Different clamp models

Models 1-5 are directly attached to the slider, without another object in between. Therefore, there are less steps required to attach the tube to the slider. However, after detaching the tube, it is difficult to replace the tube in the exact same position, since there is no indication on what the correct position is. To ensure the tubes position, model 6 is created. In this model, the tube is positioned into the clamp once, and the clamp is attached to a small block. This small block is attached to the slider. The user can take out the tube, by detaching the clamp from the block. Replacing the tube is only possible by attaching the clamp in the exact same position as before, onto the block.

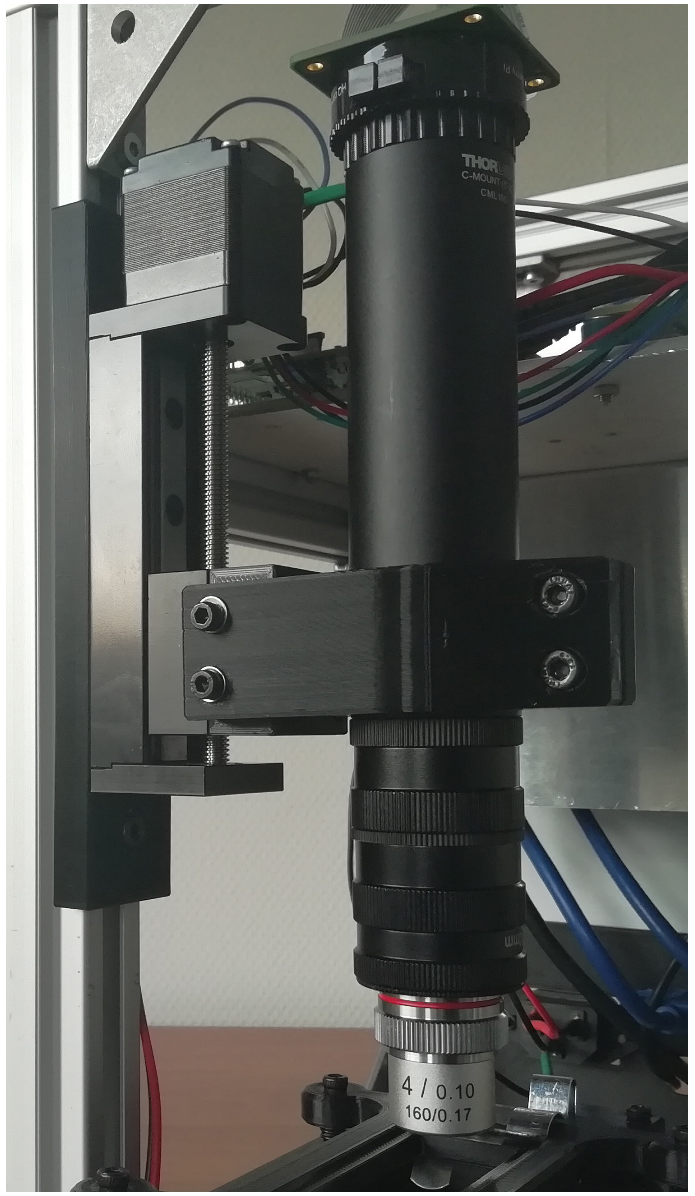


Figure 80. Clamp in Schistoscope 5

Check

The clamp ensures stability and prevents the tube from tilting. This is important to ensure image quality and for capturing the entire sample. However, the clamp design requires a relative long printing time, for the quality it delivers. The 3D-printed clamps must tightly clamp the tube to prevent rotation of the tube. The clamp from model 6 clamps tight enough, however, the connection to the block is too flexible. The 3D-prints are not rigid enough and allow for too much change in shape. Model 6 meets the requirements and scores relatively high on the four factors of strenght, printing time, ease of implementation and the contribution to alignment. However, there is room for improvement.

Act

In further research, this clamp must be evaluated and possibly redesigned, with a different production method. Additionally, off-the-shelf components that fit the dimensions to attach the tube to the slider must be considered. More about this in chapter Recommendations.

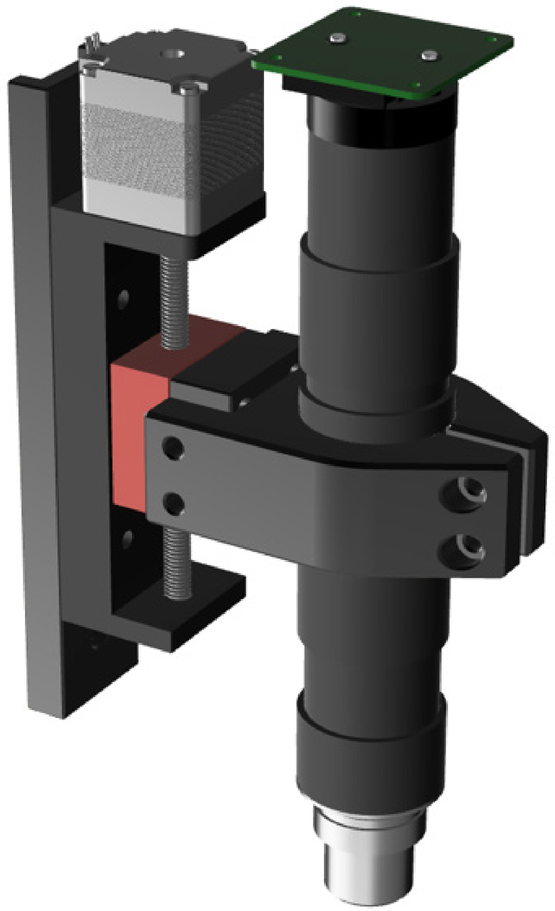


Figure 81: Model of clamp

List of Requirements 9

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm

2 The sample should always remain horizontally flat to prevent the filter from falling off

3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide

4 The device must allow for a change of glass slide

5 All materials used for the device must sustain their physical properties after being cleaned by alcohol

6 The device must allow for the use of a 4X microscope objective

7 The device must adequately illuminate the sample

8 The device must allow for the use and change of a microscope objective

9.1 Either the camera sensor or the sample must move in the focus direction, z-axis

9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis

9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis

9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis

9.5 Either the illumination or the sample must move in the short sample direction, x-axis

9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis

9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis

9.8 Either the illumination or the sample must move in the long sample direction, x-axis

9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis

10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm

11 The device must allow for levelling of the sample bed

12 The device must allow for the use of a Jetson Nano Developer board

13.1 The device must allow for the use of a Jetson Nano Camera

13.2 The device must allow for the use of a Raspberry Pi Camera

14.1 The camera sensor should be aligned with the glass slide in x- and y-direction

14.2 The camera sensor must be restricted from rotating without interaction of the user

14.3 The optical set-up mustensure alignment of camera sensor, slide and illumination

14.4 The device must ensure reliable movement

14.4 The device must ensure alignment over time

14.5 Components used to align systems should remain physically reliable over time

15 The device must operate in climate temperatures of at least 50 degrees celcius

16 The device must provide stability to the integrated systems

17.1 The device must house specific electronic components

17.2 The devicce must use a Switch Mode Power Supply to adapt voltagesA

18 The device must have a robust appearance

19 The device must enable automated x, y and z movements

20 The device must facilitate a z-movement step size of 5um

21 The weight of a component should be close to the point of applied forces

22 The total number of components should be as low as possible

23 The design must allow for a travel distance of minimal 20mm

24 The device must allow for the entire sample to be scanned

25 All axile movement should only have 1 degree of freedom, in the linear directiona

26 The set-up must be adaptable to changes in hardware

27 The device should facilitate a motorised x- and y-step size of at least 1mm

28 The device should be reproducable

Unchanged *Added* *Adapted or removed requirement*

PDCA-9

Sample stage

Plan

As mentioned before in chapter Schistoscope 4.0, a major issue from the Schistoscope 4 is the unreliability of the sample moving system. One of the causes of this unreliability is the sample stage. In the Schistoscope 4, the sample stage is a large, flat, u-shaped component. The design of this component is sensitive to shaking due to vibrations from either the stepper motors or the environment of the Schistoscope. This cycle will focus on finding a solution by redesigning the geometry of the sample stage.

Challenges

Challenge 2: Allow for different Field of View of sample

Challenge 3: Ensure consistent field of view

Do

For the purpose of this cycle, the sample stage is simplified to a cantilever beam, see figure 82. This beam is fixated at point A, similar to where the sample stage is fixated to the slider. Point B is 'floating', not fixated, or restricted. Considering the equilibration of deflection in a beam, the maximum deflection at the end of a cantilever beam can be expressed as [11]:

$$\delta B = \frac{Force \cdot Lenght^{3}}{3 \cdot E \cdot I}$$

δB = maximum deflection in point B (mm)
F = single acting force in B (N)
E = modulus of elasticity (N/mm2)
I = area moment of Inertia (mm4)
L = length of beam (mm)

From this formula follows, that for a decrease in deflection, the area moment of inertia must be increased, if the modulus of elasticity and the length remain equal.

The area moment of inertia is based on the cross section and shape of the beam. Increasing the cross section, will increase the area moment of inertia. For example, double the height of a rectangle will quadruple the area moment of inertia. However, doubling the width only doubles the area moment of inertia.

The Schistoscope 4 sample stage its width was twice its height. To decrease deflection, the area moment of inertia must increase, by adjusting the cross section. Especially increasing the height will change the area moment of inertia. Therefore, the new design has a different shape and size. The smallest cross section, at the end of the beam, is similar to the original. However, this design uses a tapered beam, the height of the cross section at the base is larger than the height at the end of the beam. As shown in figure 82, the bending moment is largest at the fixed point A. Increasing the height and thus the cross section at this point, will strengthen the beam at this point.
With this knowledge, the new design was created, optimising the shape to prevent deflection.

Figure 82. Beam deflection forces

Check

The printed model is easily attached to the slider and moves freely alongside the edge of the slider in the x-direction. Because of the off-the-shelf components, there are already less vibration due to the motors. There is no visually noticeable vibration on the sample stage when the device is running a test., when the user presses on the end of the sample stage, the stage will deflect. This happens when a user does not carefully place a sample in the sample holder. The image preview does show a vibrating image when the surface on which the device is placed is vibrating. This can be caused by the sample stage, however, there are multiple other aspects that can be of influence. This is further elaborated in chapter Schistoscope 4.0.

When testing the set-up, the stage appeared to be too small. This is due to a change of dimensions of the illumination unit. This illumination unit is out-of-scope for this graduation project. The design was provided, it only needs to be placed within the design. However, during the test session, the given design of the illumination unit is considered unsatisfactory therefore redesigned. This redesign requires larger dimension, and therefore, the sample stage changes as well.

Act

Since there is no need to redesign the whole stage, there is no need for a full PDCA-cycle. A simple adjustment to the total width of the stage can be applied and the stage can be printed again. Only after testing this new model and finding new issues, a new cycle must be run.


Figure 83. Sideview stage Schistscope 4


Figure 84. Sideview stage Schistoscope 5

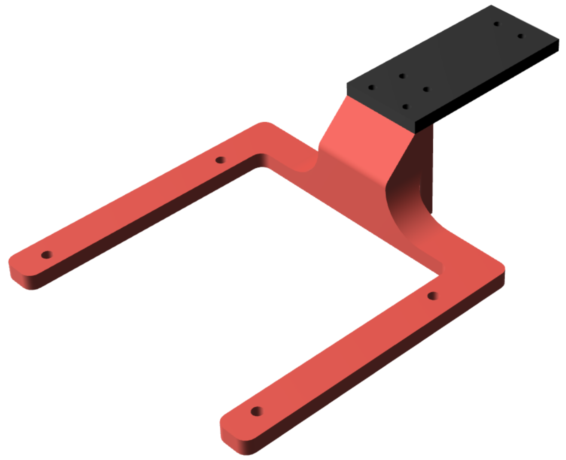


Figure 85. Stage Schistoscope 4


Figure 86. Stage Schistoscope 5


Figure 87. Stage clashing into illumination unit

List of Requirements 10

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm

2 The sample should always remain horizontally flat to prevent the filter from falling off

2.1 The moving system must not vibrate while an image is captured

3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide

4 The device must allow for a change of glass slide

5 All materials used for the device must sustain their physical properties after being cleaned by alcohol

6 The device must allow for the use of a 4X microscope objective

7 The device must adequately illuminate the sample

8 The device must allow for the use and change of a microscope objective

9.1 Either the camera sensor or the sample must move in the focus direction, z-axis

9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis

9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis

9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis

9.5 Either the illumination or the sample must move in the short sample direction, x-axis

9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis

9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis

9.8 Either the illumination or the sample must move in the long sample direction, x-axis

9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis

10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm

11 The device must allow for levelling of the sample bed

12 The device must allow for the use of a Jetson Nano Developer board

13.1 The device must allow for the use of a Jetson Nano Camera

13.2 The device must allow for the use of a Raspberry Pi Camera

14.1 The camera sensor should be aligned with the glass slide in x- and y-direction

14.2 The camera sensor must be restricted from rotating without interaction of the user

14.3 The optical set-up mustensure alignment of camera sensor, slide and illumination

14.4 The device must ensure reliable movement

14.4 The device must ensure alignment over time

14.5 Components used to align systems should remain physically reliable over time

14.6 Moving components must be restricted from clashing into other components.

15 The device must operate in climate temperatures of at least 50 degrees celcius

16 The device must provide stability to the integrated systems

17.1 The device must house specific electronic components

17.2 The devicce must use a Switch Mode Power Supply to adapt voltagesA

18 The device must have a robust appearance

19 The device must enable automated x, y and z movements

20 The device must facilitate a z-movement step size of 5um

21 The weight of a component should be close to the point of applied forces

22 The total number of components should be as low as possible

23 The design must allow for a travel distance of minimal 20mm

24 The device must allow for the entire sample to be scanned

25 All axile movement should only have 1 degree of freedom, in the linear directiona

26 The set-up must be adaptable to changes in hardware

27 The device should facilitate a motorised x- and y-step size of at least 1mm

28 The device should be reproducable

29 The dimensions of the device must be as small as possible

29.1 The design of system components must not unneccesary increase total volume of device

Unchanged

Added

Adapted or removed requirement

PDCA-10

Sample fixation

Plan

To ensure that the entire sample is captured, the glass slide must maintain the same position on the sample holder. Since glass slides can have slight changes in size throughout different suppliers, an exact fit closure is not possible. One possible solution is to fixate the sample slide onto the sample holder to secure the position. This cycle will aim to find a solution to maintain the position of the sample slide throughout a scan.

Challenges

Challenge 3: Ensure consistent field of view

Do

The first solution was implementing two standard microscope clips (figure 90 and 91). These clips are normally used in standard microscope sample stages. By sliding the glass slide underneath these clips the slide will be pressed against the stage to prevent displacement. The clips use a spring to push on end of the clip upwards and thereby pushing the other end downwards. If implemented in the Schistoscope, the use of these clips will be different. Instead of sliding underneath, the clip must be push, turned and released on top of the slide.

Another off-the-shelf solution is tool clamp, used to clamp cylindrical instruments. The shape of these clamps creates a certain pressure that can hold an object. There is a gap in the middle of the clamp, which allows for mounting onto the sample holder. By integrating this clamp around the sample holder, one side of the clamp will press the slide on the holder.

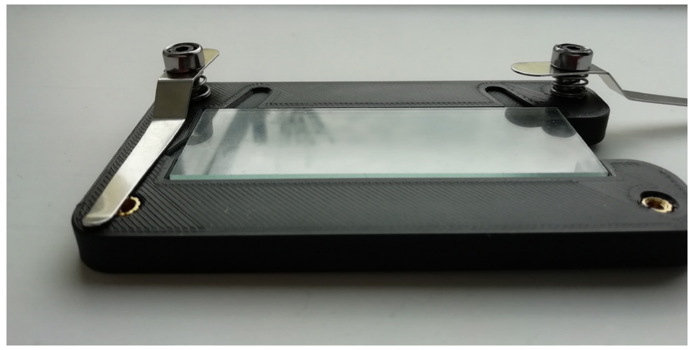


Figure 90.Sample not fixated

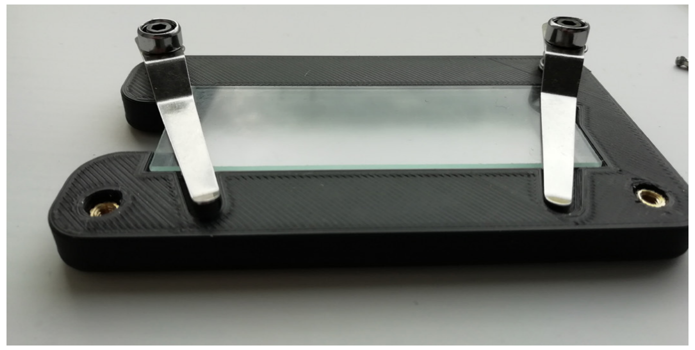


Figure 91. Sample fixated with two microscope clips

Check

Both clips were analysed on their influence on fixation and alignment of the glass slide. Figure 93 show that ineffective implementation of any clip can cause tilting in the slide, which will cause misalignment with the image sensor.

Both clips were tested by users. The microscope clip was perceived as a difficult to use, it requires an additional action in the sample placement process. Additionally, there is a high possibility of accidentally placing the clip on the filter and thereby damaging the sample.

The advantage the tool clamp compared to the microscope clip, is that the tool clamp only requires the user to press the glass slide underneath the clamp. However, the user feedback reveals that users feel uncomfortable when pressing the glass against the metal clamp. The users are afraid of damaging the glass slide by pressing hard against the metal. The resistance of metal against glass was too high in this design.

Act

In consultation with the experts and researchers in the field, the decision is made to not include a sample fixation in the Schistoscope 5. The glass slide is placed into a dedicated slot, with dimensions close to the glass slide. With the implementation of the new off-the-shelf sliders, the vibrations that cause the glass slide to change positions are minimal. Plus, the glass slide cannot move more than 1mm since the slot prevents further displacement.

The experts expressed their preference to not fixating the glass slide above an additional user action like the microscope clip. However, additional research into fixating the sample, or preventing the sample from displacing must be executed.

Figure 92 Sample fixated with a tool clamp

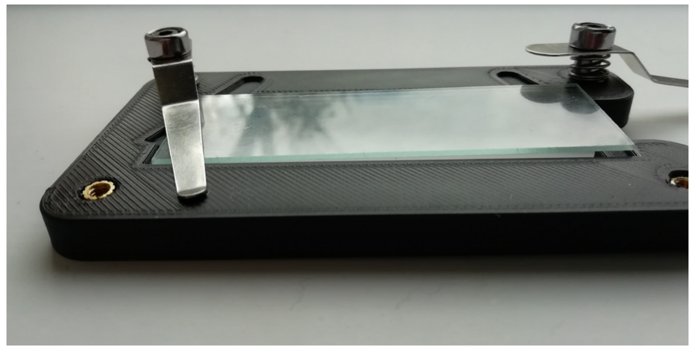


Figure 93 Tilt in sample due to wrong fixation

List of Requirements 11

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm

1.1 The device must allow for the scanning of glass slides with slight tolerances from the standard size

2 The sample should always remain horizontally flat to prevent the filter from falling off

2.1 The moving system must not vibrate while an image is captured

3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide

4 The device must allow for a change of glass slide

5 All materials used for the device must sustain their physical properties after being cleaned by alcohol

6 The device must allow for the use of a 4X microscope objective

7 The device must adequately illuminate the sample

8 The device must allow for the use and change of a microscope objective

9.1 Either the camera sensor or the sample must move in the focus direction, z-axis

9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis

9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis

9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis

9.5 Either the illumination or the sample must move in the short sample direction, x-axis

9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis

9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis

9.8 Either the illumination or the sample must move in the long sample direction, x-axis

9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis

10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm

11 The device must allow for levelling of the sample bed

12 The device must allow for the use of a Jetson Nano Developer board

13.1 The device must allow for the use of a Jetson Nano Camera

13.2 The device must allow for the use of a Raspberry Pi Camera

14.1 The camera sensor should be aligned with the glass slide in x- and y-direction

14.2 The camera sensor must be restricted from rotating without interaction of the user

14.3 The glass slide must be restricted from moving in the sample holder without interaction of the user

14.4 The optical set-up mustensure alignment of camera sensor, slide and illumination

14.4 The device must ensure reliable movement

14.5 The device must ensure alignment over time

14.6 Components used to align systems should remain physically reliable over time

14.7 Moving components must be restricted from clashing into other components.

15 The device must operate in climate temperatures of at least 50 degrees celcius

16 The device must provide stability to the integrated systems

17.1 The device must house specific electronic components

17.2 The devicce must use a Switch Mode Power Supply to adapt voltagesA

18 The device must have a robust appearance

19 The device must enable automated x, y and z movements

20 The device must facilitate a z-movement step size of 5um

21 The weight of a component should be close to the point of applied forces

22 The total number of components should be as low as possible

23 The design must allow for a travel distance of minimal 20mm

24 The device must allow for the entire sample to be scanned

25 All axile movement should only have 1 degree of freedom, in the linear directiona

26 The set-up must be adaptable to changes in hardware

27 The device should facilitate a motorised x- and y-step size of at least 1mm

28 The device should be reproducable

29 The dimensions of the device must be as small as possible

29.1 The design of system components must not unneccesary increase total volume of device

Unchanged | *Added* | *Adapted or removed requirement*

PDCA-11

Sample holder

Plan

The Schistoscope 4 sample holder was created to provide the user with the possibility to place two sizes of glass slides. The availability of glass slides differs per country and the Schistoscope aims to be commonly applicable. Therefore, the possibility for enabling two sizes is preferable. However, this graduation project aims for the use case of a field study. During this study, the size of the glass sides is set to be of size 26x76mm. Thus, the sample holder can be redesigned for the use of one size sample slide. This cycle must also explore the possibility of the method for sample insertion.

Challenges

Challenge 2: Allow for different Field of View of sample

Challenge 3: Ensure consistent field of view

Do

The Schistoscope 4 places the sample into a slot over the long side of the slide. However, in standard microscopy, the sample is put on a table surface and slid underneath specimen clips, over the short side. Executing a small user test, with six participants, researched the possibility of inserting the sample into a slot over the short side. Figures 94-98 show the different ways the user must hold the sample when placing the slide into the holder. The test subjects differed from design, non-design, medical and non-medical participants.

When allowed to hold the sample in any way possible, the results of the user's preference were divided. However, after explaining the intended use of the glass slide and the placement of the filter on the glass slide, their actions changed. The users experienced that the risk of contaminating the filter, due to improperly touching the slide, restricted their options. The areas that are available for the user to hold the slide in between their fingers are few, and they clash with the sample holder when inserting the sample. All six participants expressed a preference for inserting the slide the same way as in the Schistoscope 4, due to this risk of contamination.

Figure 94. Long side insertion

Figure 95. Long side insertion

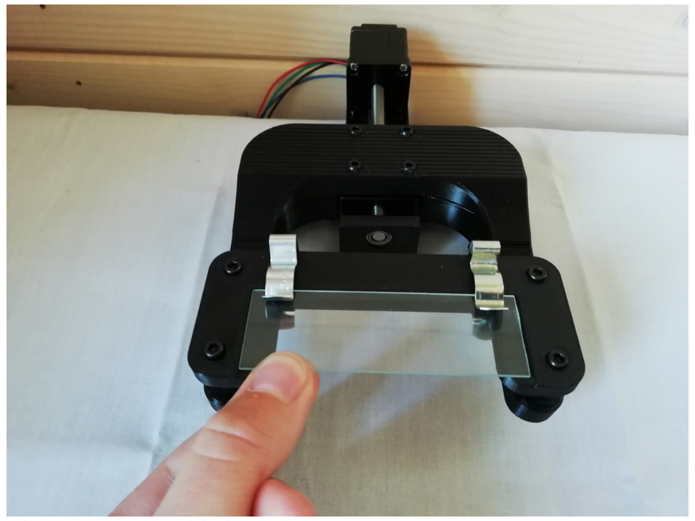


Figure 96. Short side insertion

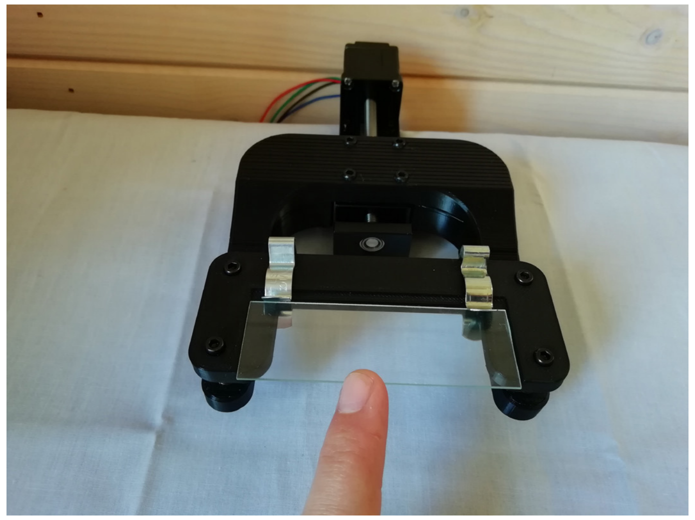


Figure 97. Short side insertion

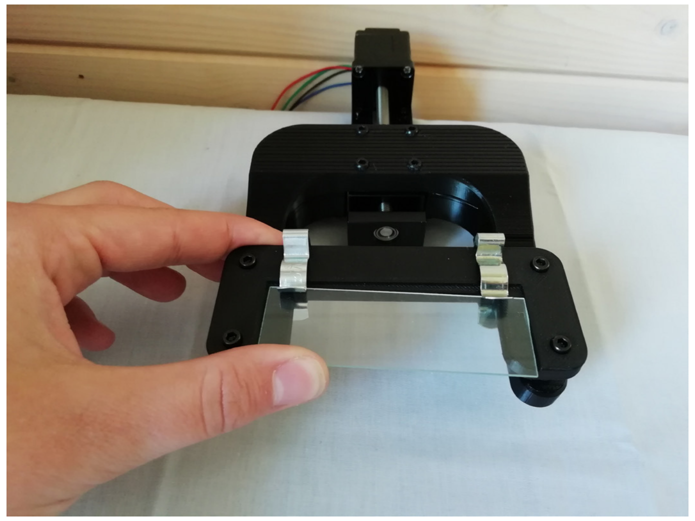


Figure 98: Short side insertion

Check

Even though the outcome of this user test restricts design freedom, the sample holder is one of the few components the user directly interacted with. Therefore, the usability factor is the most important aspect. One simple request from the medical PhD-student was to ensure the ability of the device to capture the entire filter, and simultaneously allow for the use of a 25mm filter. A small adjustment to the design was made (figure 100). The contact surface in the middle, the most common place to put the filter, is removed. Thereby, the total contact surface is decreased, but the glass slide is still supported at both ends.

Act

The next designs must ensure the insertion of the glass slide over the long side. It must also be considered to allow the use for a second size of glass slide, 76x26mm. This allows for a wider applicability since the user is not limited to a specific size. Furthermore, the possibilities of fixating or pinning the glass slide onto the sample holder must be researched. show insights gathered during this graduation project about clips and fixation, however it is not further elaborated in a design.

Figure 99. Sample holder A

Figure 100. Sample holder B, with additional hole

List of Requirements 12

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm
1.1 The device must allow for the scanning of glass slides with slight tolerances from the standard size
2 The sample should always remain horizontally flat to prevent the filter from falling off
2.1 The moving system must not vibrate while an image is captured
3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide
4 The device must allow for a change of glass slide
5 All materials used for the device must sustain their physical properties after being cleaned by alcohol
6 The device must allow for the use of a 4X microscope objective
7 The device must adequately illuminate the sample
8 The device must allow for the use and change of a microscope objective
9.1 Either the camera sensor or the sample must move in the focus direction, z-axis
9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis
9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis
9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis
9.5 Either the illumination or the sample must move in the short sample direction, x-axis
9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis
9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis
9.8 Either the illumination or the sample must move in the long sample direction, x-axis
9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis
10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm
11 The device must allow for levelling of the sample bed
12 The device must allow for the use of a Jetson Nano Developer board
13.1 The device must allow for the use of a Jetson Nano Camera
13.2 The device must allow for the use of a Raspberry Pi Camera

14.1 The camera sensor should be aligned with the glass slide in x- and y-direction
14.2 The camera sensor must be restricted from rotating without interaction of the user
14.3 The glass slide must be restricted from moving in the sample holder without interaction of the user
14.4 The optical set-up mustensure alignment of camera sensor, slide and illumination
14.4 The device must ensure reliable movement
14.5 The device must ensure alignment over time
14.6 Components used to align systems should remain physically reliable over time
14.7 Moving components must be restricted from clashing into other components.
15 The device must operate in climate temperatures of at least 50 degrees celcius
16 The device must provide stability to the integrated systems
17.1 The device must house specific electronic components
17.2 The devicce must use a Switch Mode Power Supply to adapt voltagesA
18 The device must have a robust appearance
19 The device must enable automated x, y and z movements
20 The device must facilitate a z-movement step size of 5um
21 The weight of a component should be close to the point of applied forces
22 The total number of components should be as low as possible
23 The design must allow for a travel distance of minimal 20mm
24 The device must allow for the entire sample to be scanned
25 All axile movement should only have 1 degree of freedom, in the linear directiona
26 The set-up must be adaptable to changes in hardware
27 The device should facilitate a motorised x- and y-step size of at least 1mm
28 The device should be reproducable
29 The dimensions of the device must be as small as possible
29.1 The design of system components must not unneccesary increase total volume of device
30 The glass slide must be placable without the user interfering with the sample

Unchanged *Added* *Adapted or removed requirement*

PDCA-12

Supporting system

Plan

One insight from PDCA-cycle 12 is the opportunity to divide movement and support instead of combining them with limited results. As long as the project remains dynamic, dividing moving systems from support and enclosure systems is desirable. Splitting all systems into separate systems that are combined into one device, allows for easy adaptations. The goal for the supporting system is that it must easily support a different enclosure design, or another moving system.

In the Schistoscope 4, the supporting system is combined with the enclosure system. The acrylic plates act as walls, but also provide a certain degree stability. The acrylic plates in the prototype are joint using 3D-printed corner joints with thread inserts. The acrylic plates have a relative high thickness of 6mm, however there is still a visible displacement of the optical train because of deflection and vibration of the acrylic plate due to rotating and vibrations of the motors. The aim for this cycle is to find a solution that ensures reliability and stability of all the other systems.

Challenges

Challenge 5: Provide stability of all systems inside the device

Do

The use of aluminium profiles is a result from the exploration of Z-triangle, PDCA-cycle 5. When exploring the difficulties that arose in the z-triangle cycles, the use of aluminium profiles as combined guiding and supporting system was considered. However, in cycle 12, the decision to divide guiding and supporting systems was made. Still, the aluminium profiles can create the needed supporting system in a suitable way. The profiles allow for easy attachment of other systems and the corner joint allow for quick adaptations is requested. Aluminium profiles are widely used for 3D-printers, CNC-machinery, and research test set-ups.

The frame is constructed by attaching profiles with metal corner joints and creating rectangle constructions. The frame uses several multiple profiles to allow for change and attachment of an enclosure. The set-up creates multiple rectangles to increase rigidness. The bottom profiles prevent the device from tilting forwards, The upper profiles prevent the vertical profiles from leaning, and the middle profiles allow for the mounting of an electronics panel.

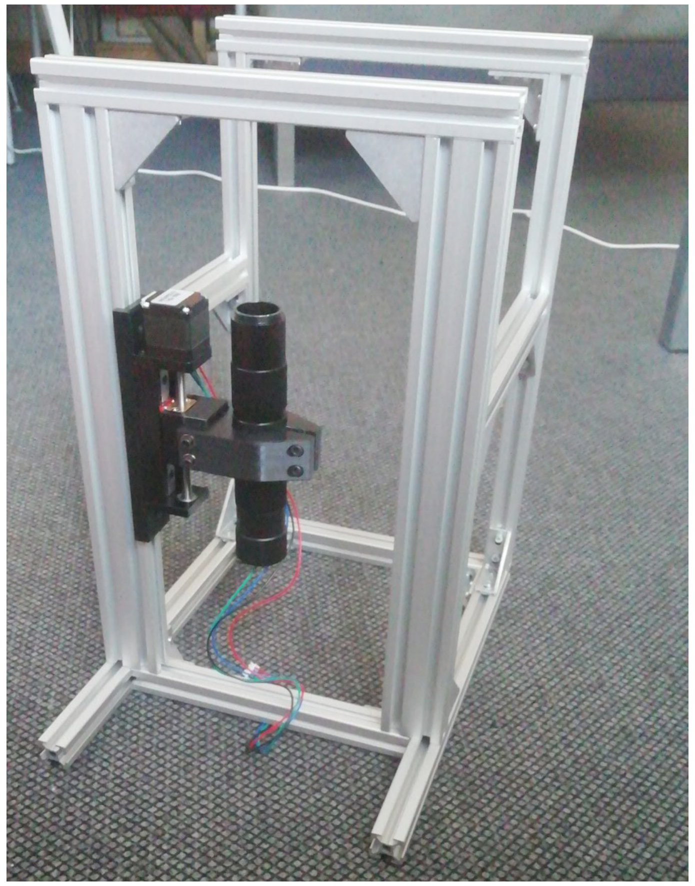


Figure 101 Frame of Schistoscope 5

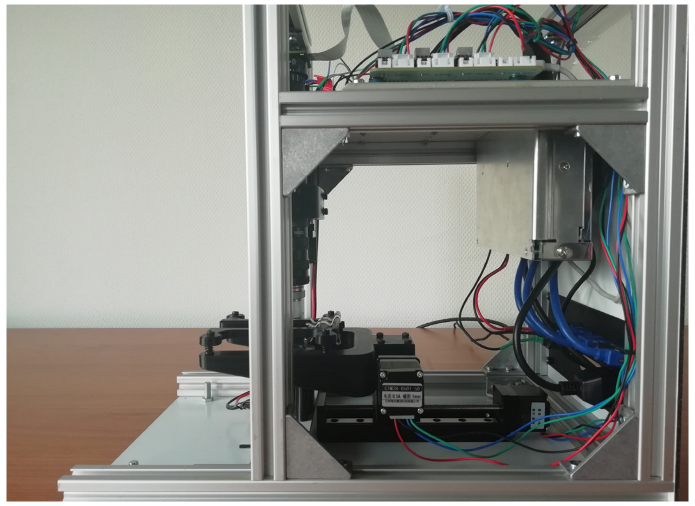


Figure 102 Sideview Schistoscope 5, without enclosure

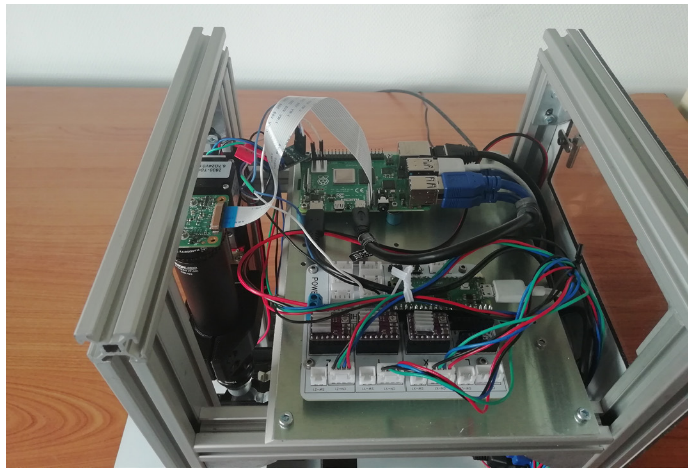


Figure 103 Topview Schistoscope 5, without enclosure

Check

The main requirement for this system is the adaptability and stability. The number of profiles used ensure a maximum stability and still allow for certain adaptation. The other systems are mounted onto the frames and without much change of the supporting system, different systems can be mounted as well. Because of the shape of the aluminium profiles and the use of slider nuts, components are easily attached to the frames requiring changes to the profiles or components. Where most materials require non-reverse modifications to mount other components, the aluminium frames are not modified at all.

Act

Aluminium is a limited natural resource and less than eco-friendly production process and is therefore considered an unsustainable solution. The current design uses more than 3 meters of aluminium 2020 frames. The aim was stability. This number of aluminium frames ensure that stability. However, the design could be optimized from a sustainable perspective. Chapter Recommendations provides the project with suggestions to continue and aspects that require more research and attention.

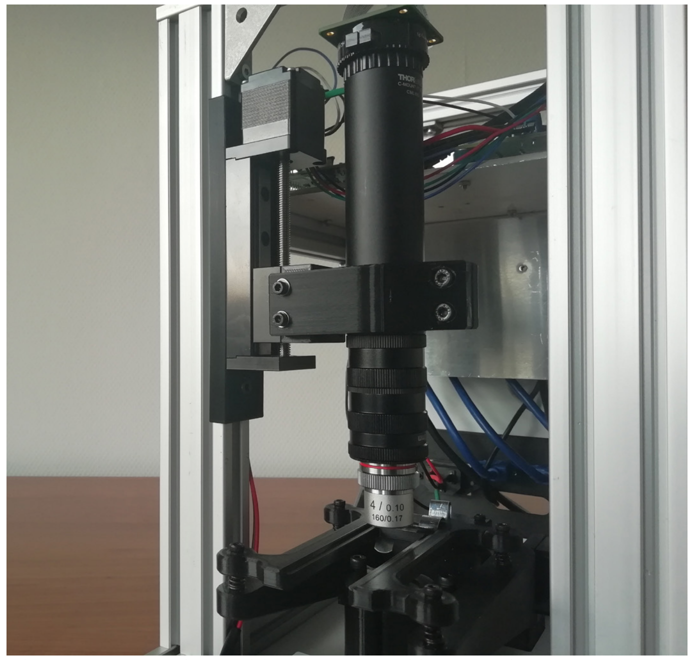


Figure 104 Frontview Schistoscope 5, without enclosure

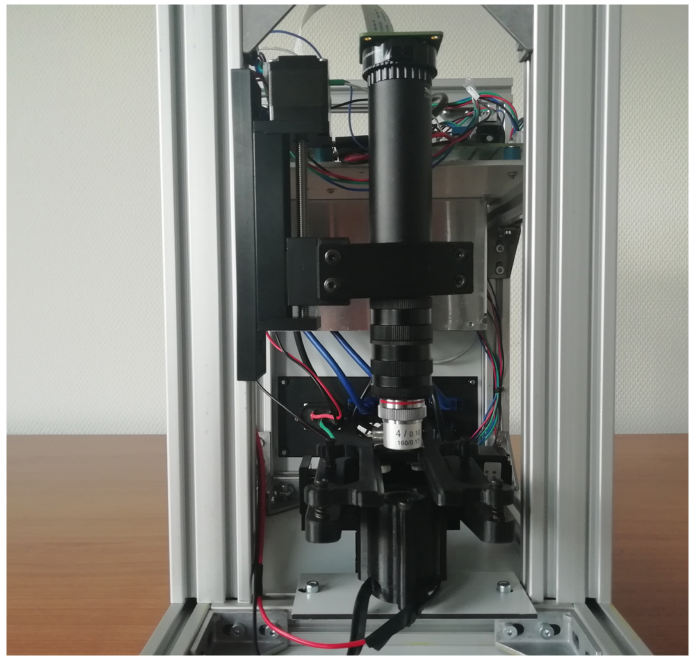


Figure 105 Frontview Schistoscope 5, without enclosure

List of Requirements 13

1 The device must allow for the scanning of a standard size glass slide, size 26 mm by 76 mm
1.1 The device must allow for the scanning of glass slides with slight tolerances from the standard size
2 The sample should always remain horizontally flat to prevent the filter from falling off
2.1 The moving system must not vibrate while an image is captured
3 The device must be able to scan the entire 13 mm filter placed at any position of a glass slide
4 The device must allow for a change of glass slide
5 All materials used for the device must sustain their physical properties after being cleaned by alcohol
6 The device must allow for the use of a 4X microscope objective
7 The device must adequately illuminate the sample
8 The device must allow for the use and change of a microscope objective
9.1 Either the camera sensor or the sample must move in the focus direction, z-axis
9.2 The illumination and the sample must remain at the same distance in the focus direction, z-axis
9.3 The illumination and the camera sensor have no relative movement in the focus direction, z-axis
9.4 Either the camera sensor or the sample must move in the short sample direction, x-axis
9.5 Either the illumination or the sample must move in the short sample direction, x-axis
9.6 The illumination and the camera sensor must move equally in the short sample direction, x-axis
9.7 Either the camera sensor or the sample must move in the long sample direction, y-axis
9.8 Either the illumination or the sample must move in the long sample direction, x-axis
9.9 The illumination and the camera sensor must move equally in the long sample direction, x-axis
10 The distance between the camera sensor and the bottom of the objective thread must be 160 mm
11 The device must allow for levelling of the sample bed
12 The device must allow for the use of a Jetson Nano Developer board
13.1 The device must allow for the use of a Jetson Nano Camera
13.2 The device must allow for the use of a Raspberry Pi Camera

14.1 The camera sensor should be aligned with the glass slide in x- and y-direction
14.2 The camera sensor must be restricted from rotating without interaction of the user
14.3 The glass slide must be restricted from moving in the sample holder without interaction of the user
14.4 The optical set-up mustensure alignment of camera sensor, slide and illumination
14.4 The device must ensure reliable movement
14.5 The device must ensure alignment over time
14.6 Components used to align systems should remain physically reliable over time
14.7 Moving components must be restricted from clashing into other components.
15 The device must operate in climate temperatures of at least 50 degrees celcius
16 The device must provide stability to the integrated systems
17.1 The device must house specific electronic components
17.2 The devicce must use a Switch Mode Power Supply to adapt voltagesA
18 The device must have a robust appearance
19 The device must enable automated x, y and z movements
20 The device must facilitate a z-movement step size of 5um
21 The weight of a component should be close to the point of applied forces
22 The total number of components should be as low as possible
23 The design must allow for a travel distance of minimal 20mm
24 The device must allow for the entire sample to be scanned
25 All axile movement should only have 1 degree of freedom, in the linear directiona
26 The set-up must be adaptable to changes in hardware
27 The device should facilitate a motorised x- and y-step size of at least 1mm
28 The device should be reproducable
29 The dimensions of the device must be as small as possible
29.1 The design of system components must not unneccesary increase total volume of device
30 The glass slide must be placable without the user interfering with the sample

Unchanged

Added

Adapted or removed requirement

PDCA-13

Enclosure system

Plan

To prevent the systems inside the device from being affected by external factors, this cycle will address the need for an enclosure system. The enclosure will protect the device from dust, damp, or accidental interference by humans. The system should be robust, easy to clean and transportable.

Appendix D shows a result from additional research into medical aesthetics and the factors that require attention when improving the appearance of the Schistoscope. To conclude appendix D, the following three areas for improvements are identified:

improving the unity.

Unity: is it unified, does it strike you as a coherent whole?

decreasing the variety to a lower level

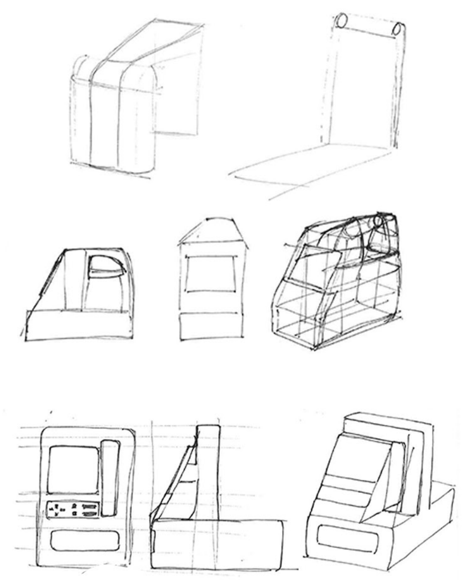
Variety: are there many different elements, do the composing elements differ?

slightly Improving the typicality.

Typicality: is it a common design, do you easily recognize it as belonging to a particular product type or range?

Challenges

Challenge 6: Create a barrier between the systems and the environment



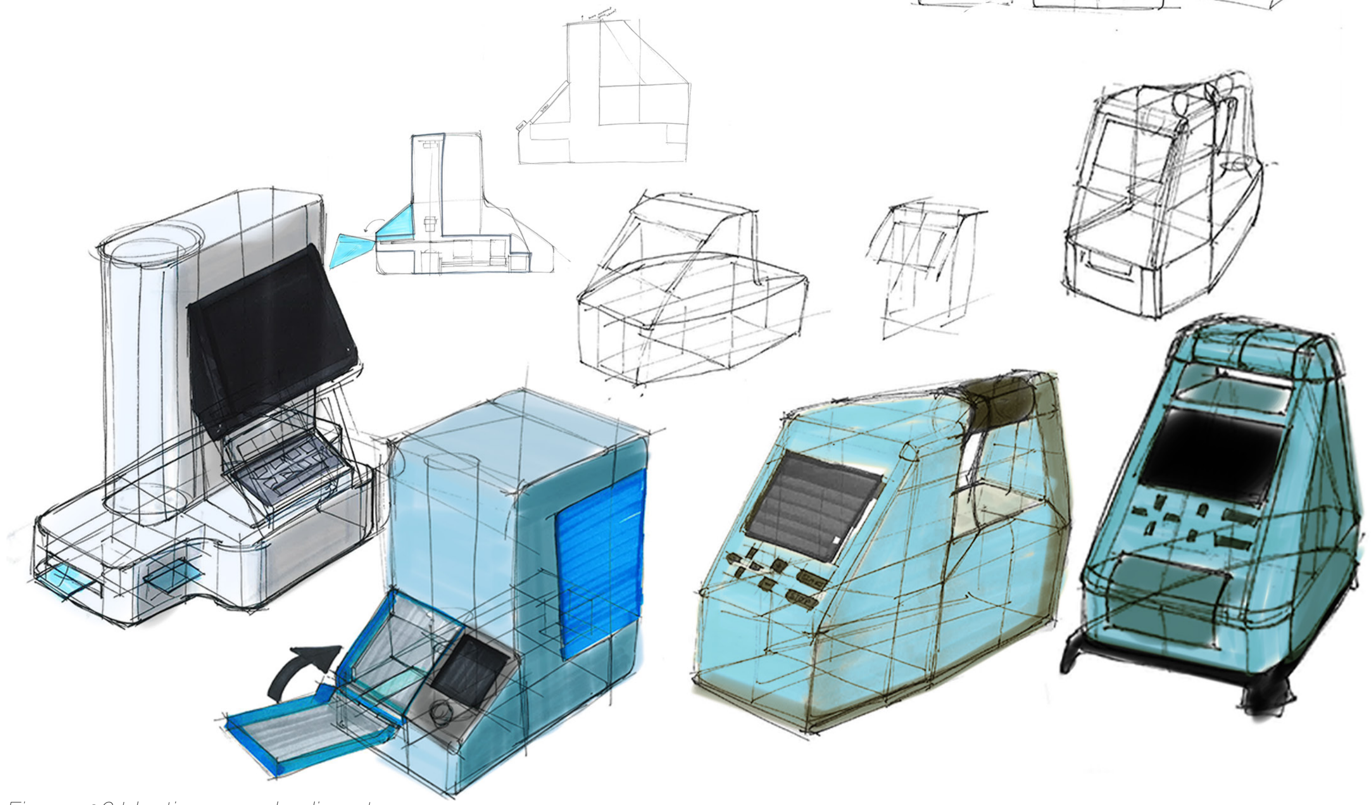


Figure 106 Ideation on embodiment

Do

While prototyping in other cycles, a material called 'Alubond' was on hand and used to create rapid prototypes. When designing the enclosure system, the other systems were not completely defined, therefore, the dimensions were not yet set. There was a request for an enclosure that could be created and adapted quickly. Alubond has a relative low price, €25,56/m2 (thickness 3mm). For example, an acrylic plate of 3mm thickness costs €35,02/m2. Furthermore, an Alubond plate of 3mm can resist more force than an acrylic plate of 3mm. Acrylic plates with a thickness of 8mm cost around €125,75/m2 [24].

Furthermore, Alubond is light weight, easy to clean, maintenance free. It has a very low expansion coefficient, which does differ per thickness and suppliers. The material allows for production with laser cutting, CNC-milling, sawing and drilling. It even allows for printing, which could provide possibilities in the future, for example printing a Schistoscope logo or use-cues to guide the user in operating the device.

In collaboration with the Dutch company Voordeligkunstof.nl, an enclosure was created. The design provides a good solution for quick production with a low price of €38,65 per prototype.

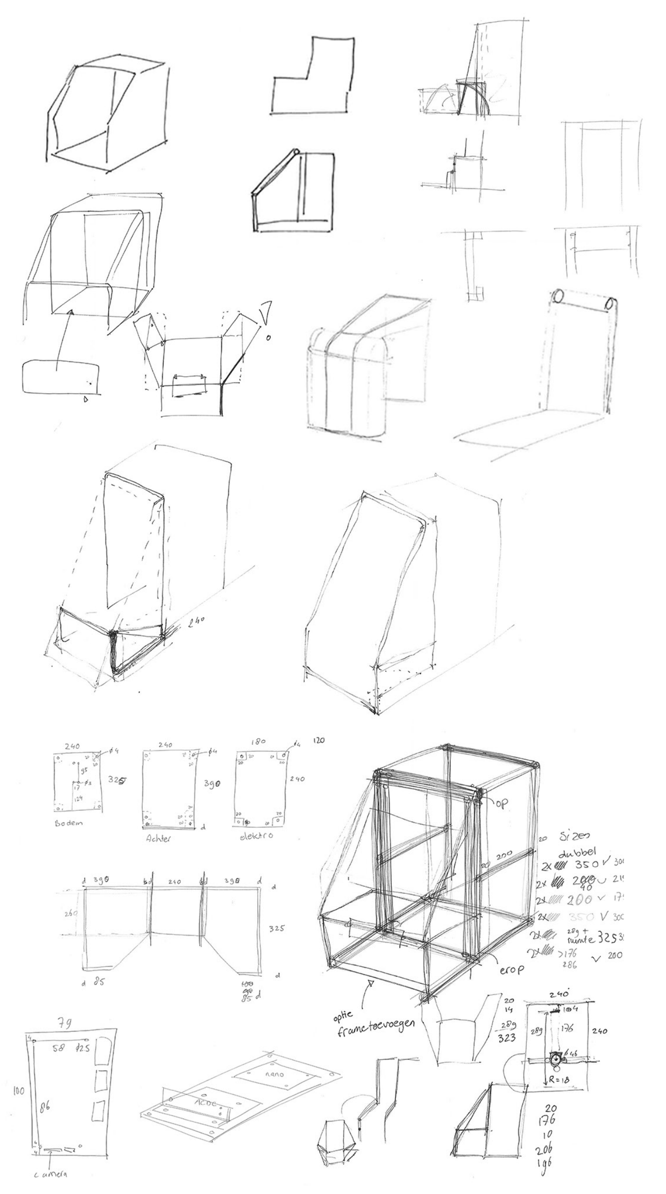


Figure 107 Sketches on applying Alubond

Figure 108 Alubond

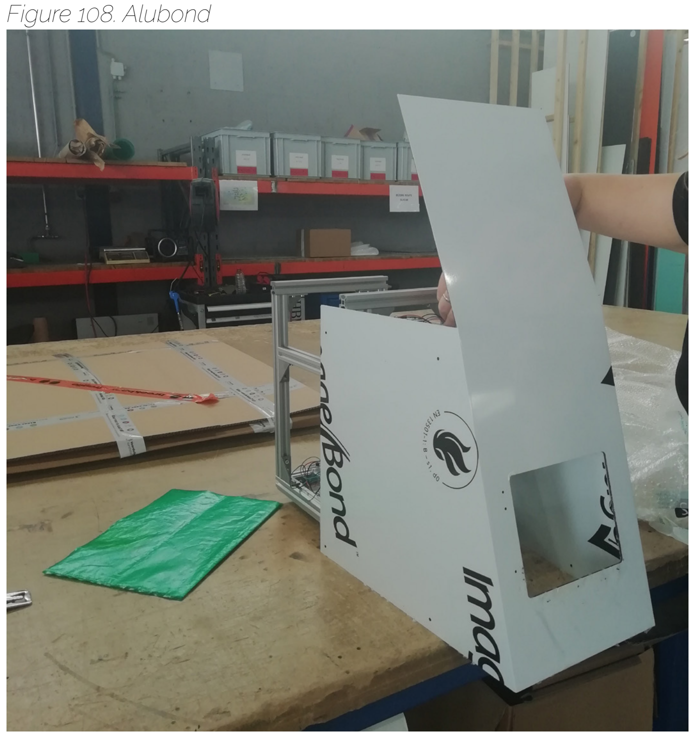


Figure 109 : Lasercutted plate for enclosure

An opening in the frontside of the device allows for the user to place the sample and to change the objective. In the back, there is another, smaller door, which allows the user to reach the electronics if needed. This is useful, if for example, a cable gets loose and needs to be reattached or when a new software update must be uploaded onto the computer. Additionally, at the backside of the product a panel is created, where all the cables to operate the device can be connected. An on-off switch in this panel provides the user with the possibility of turning off the device while keeping it connected to the power grid.

Figure 110.: Inside of Schistoscope 5

Figure 111. Backside with door and panel

Figure 112. Frontside with door

Figure 113. Cable panel

Figure 114 Electronics door

Check

The enclosure systems meet the most important requirements. It is robust and attaches easily onto the supporting system. The surface is easy to clean and the white colour resembles a medical device. In comparison to the Schistoscope 4, the unity is improved. Even though the unity is due to the existence of the enclosure rather than a specific choice in design, the unity is improved, which was one of the goals. Furthermore, another goal to decrease the variety is achieved. There is a consistency within the components used among the different systems. Both movement systems use the same off-the-shelve black sliders and most of the other components are black, white, or metal. The variety from the Schistoscope 4 was partly due to the electronics being on top of the device, very visible and chaotic with all the cables and blinking LEDs. In the Schistoscope 5, the electronics are less visible when being in front of the device.

However, there is still room for improvement of typicality and aesthetics. The design can use more medical typicality. Besides the surface being white, there are no real indications for the device being medical. However, the device is improved on typicality, only not on medical aspects, but on the aspect of 'being a device'. Because of the enclosure, the prototype becomes a real device. More about this in chapter Evaluation.

Act

Additional research must be done into medical typicality and aesthetics. Especially medical typicality in Africa. Western medical devices can look different then those in the Global South. Furthermore, large user test must be executed to gain insights in the user experience and interaction with the enclosure system. Chapter Evaluation addresses initial insights from a user test.

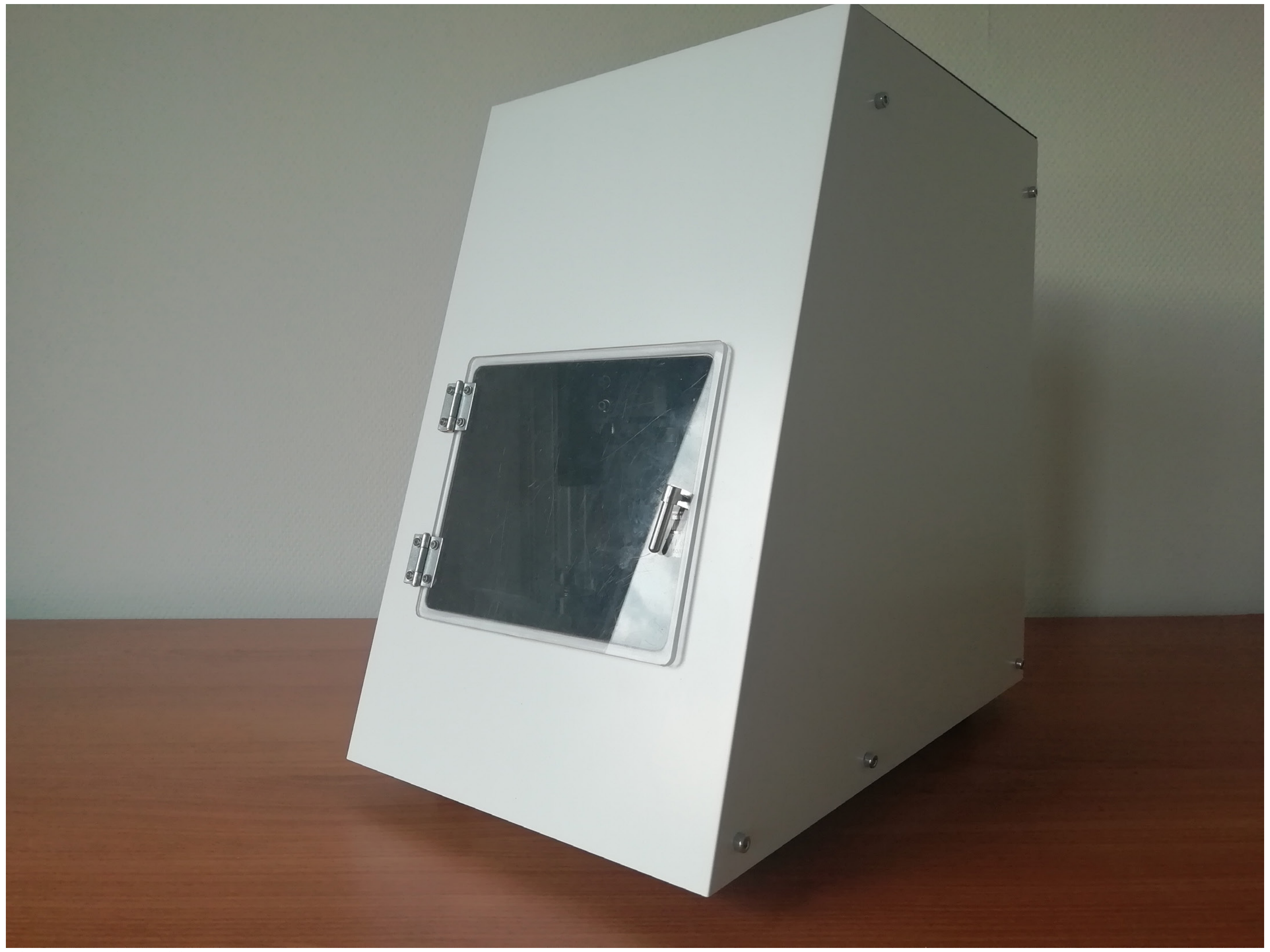


Figure 115 The Schistoscope 5

List of Requirements 14

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28 The device should be reproducable

29 The dimensions of the device must be as small as possible

29.1 The design of system components must not unneccesary increase total volume of device

30 The glass slide must be placable without the user interfering with the sample

31 All systems inside the enclosure must be protected

32 The enclosure system must be seperate from the supporting system until the hardware is fully defined

Unchanged

Added

Adapted or removed requirement

Figure 116.Field test Nigeria, 2021

4 Discussion

This chapter will discuss the final design of the Schistoscope 5. An evaluation will cover observations on usability and design based on weekly user tests. Furthermore, the image quality and estimated price of the Schistoscope are evaluated.

In the conclusion the challenges, subgoals and main goal are discussed. By completing the challenges, the design will achieve the goals formulated. The challenges and goals are stated in chapter Design Brief. Together the challenges and goals guide the design process and help validate the final design in this chapter.

Lastly, this chapter addresses multiple recommendations for further development of the Schistoscope. The first part elaborates on the main recommendations for the next iteration, the Schistoscope 6. The second and third part elaborate on two other, scenarios, with a relatively longer time frame.

Evaluation on usability

The device has been developed and tested on user experience during user tests that happened once a week, for a period of two months. These tests were performed by several context experts. During these weekly sessions, the users are observed and their reactions and concerns while operating the Schistoscope 5 were noted. These weekly sessions were also used for validating outcomes of PDCA-cycles. The observations discussed in this chapter are about the final design and therefore no iterations are made based on the outcomes of this evaluation.

Set-up user test

After completing the first user test, it became clear that the participants felt uncomfortable to express their concerns and opinions when asked to follow instructions and answer direct questions. Their reactions would be limited to what they liked, and thought was good. Their answers were mainly positive, avoiding negative reactions to protect personal relationships as colleagues. Cultural differences can play a role in how people react and give feedback.
Therefore, the decision was made to observe the participants without a strict protocol and premeditated questions. This way, the participants were not forced to express positive reactions or reactions at all. Instead, the participants were observed while being in a comfortable setting, performing an open dialogue together. In this dialogue, they felt safe to react on the device and criticise about the design decisions.

Observations

1. Attach external devices in set-up

Observations

To attach cables and external devices, the user needed to make connections at the backside of the device (figure 119). This position at the back, combined with the size of the device made it difficult to attach the cables during initial set up.

Consideration

This issue only occurs during set up, when the user needs to connect the external devices and is therefore considered a minor problem. However, when trying to optimise the device, an alternative position of the connection panel to external devices could be considered.

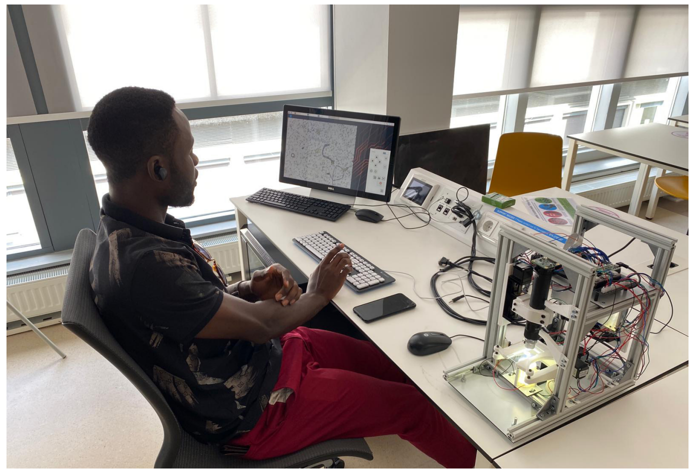

Figure 117 User test Delft 2021

2. Open and close door

Observations

The size of the doorhandle was chosen to limit additional length in front of the device (figure 118). However, the doorhandle was perceived as too small. Furthermore, the tilt of the door increased the difficulty of opening and closing the door. Lastly, the door could not open 180 degrees, and therefore not align with the front surface of the device (figure 120) This was observed as obstructive for the user.

Consideration

The door must easily be opened and aligned with the device when opened. Also, the door should be an integrated part with the rest of the enclosure. Furthermore, preferably, the door must stay at the angle of preference, meaning the door cannot open or close without a user-interaction. Considering these specifications, the current door is unsatisfactory and requires an additional iteration.

Figure 118. Doorknob Schistoscope 5

Figure 119. Cable panel Schistoscope 5

3. Place a sample

Observations

The design of the sample holder influenced how users experienced the Schistoscope. During one of the tests, a participant indicated that newly integrated design was received having a more professional and medical appearance. The design had a different shape and was 3D-printed in white plastic instead of black.

Consideration

The response on the increased professional and medical appearance of the device can be linked to three aspects of the new design. Firstly, the shape of the sample holder is changed from a lean minimalistic shape to a robust shape. This could be perceived as an improved professional look. Secondly, the new design is 3D-printed with white plastic instead of black, fitting medical appearances. Thirdly, the changed perception of the sample holder could also be related to a change of colour, relative to the other parts within the device. Where the first design was black, among other black components, the new design stood out, because the colour was different.

The different colour could have drawn extra attention of the user to the component. Considering this user experience, one might suggest changing the colour of parts that need to attract attention from the user. This could be a change to white, increasing the medical and professional appearance, however, white plastic also change colour quickly, damage is easily noticeable and can be perceived as cheap looking. Changing to a different colour can also be considered.

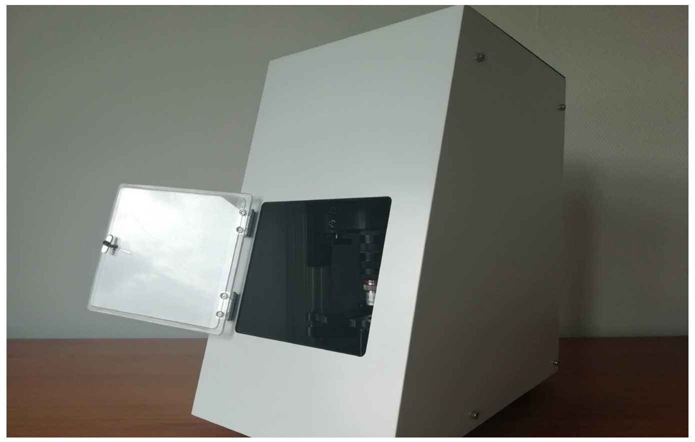

Figure 121. Open door of Schistoscope 5

4. Fixate glass slide

Observations

As a result of PDCA-cycle 10, no glass slide fixation was included in the final design. Without a fixation possibility, it was not possible to ensure that the entire sample was captured. A manual check was required to validate the results. An additional observation was that the glass slide does not move during a normal scan.

Consideration

While the lack of certainty on capturing the full sample could be problematic, it is worth noting that a microscopist using a manual adjustment stage cannot ensure capturing the entire sample as well. This unreliability is due to the difficulty of manually adjusting the same proportion to the slide position with a manual stage.

Another consideration is that the vibrations from the device itself are not large enough to shift the position of the glass slide. Only when brute forces from outside the device create vibrations, there is a small possibility that the glass slide moves, within the designated slot. Even then, the maximum displacement is only 1 mm.

However, the Schistoscope should be an improvement on standard microscopy, therefore it is essential to increase certainty on capturing the full sample when using the device in next iterations.

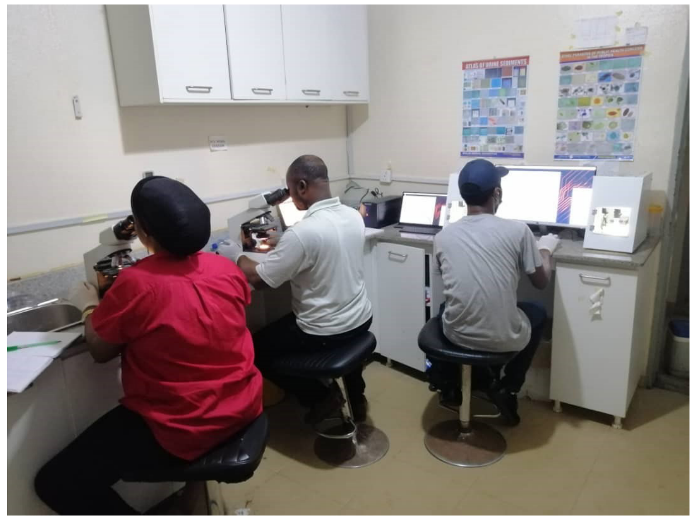

Figure 121. Schistoscope 5 in Nigerian laboratory

5. Manually analyse sample

Observations

During the weekly test sessions, several discussions on the relation between the keyboard and image preview on the display were held. Essentially the question was whether the keys relate to the image preview or the position of the sample within the device. For example, clicking the right arrow key could take the user to the FoV to the right of the previous image preview, by moving the sample one step to the left, or move the sample one step to the right inside the device, and thus moving the image preview to the left.

Consideration

Whether using the first or the latter of the two options is entirely a question of user preference. Based on the observations in this user test, users have a slight preference to relating the keys to the preview image (first option). However, from a device perspective the second option can be argued as well.

6. Start an automated scan

Observations

The software used in the current design needed to initiate the scan at one particular area, the top of the filter membrane. However, it was observed that especially the more medically inclined user experienced this as difficult, unsure whether the correct position had been found. The decision for manually positioning the sample in the starting position is based on software difficulty.

Consideration

While the issue is easily addressed by properly instructing users before usage, it is a larger issue with usability versus technical complexity. Where the technical solution now has the upper hand, in time, a shift of focus to usability aspects is necessary. This includes the software being able to find the filter on the glass slide automatically.

7. Gather results of scan

Observations

When the users wanted to collect the data and transfer it to the device that runs the algorithm, they needed to plug an USB drive into the USB port in the back of the device. As mentioned before in evaluation 1, reaching this back panel is difficult when the device is already setup and operational.

Consideration

This issue will seize to exist when the algorithm is included as an integral part of the device. However, as long as integrating the algorithm is not feasible, it would be an improvement to integrate one USB slot on a more accessible position on the device.

Evaluation on quality

Observation

As shown in figure 122 and 123, Schistoscope 5 images were different from Schistoscope 4 images. Figure 124 shows the egg detection of images captured by the Schistoscope 5. During the project, the focus shifted from aiming for the same image quality as the Schistoscope 4, to ensuring a certain benchmark image quality with the Schistoscope 5. Therefore, the quality of the image itself was still important, however far more important was the consistency of the quality throughout a range of images taken by the device.

Consideration

Based on the results of the algorithm, it can be concluded that the Schistoscope 5 delivers qualitative images. The iterations on stability and reliability became more important, not only for capturing the entire image, but also ensuring that all images have a minimal level of quality.

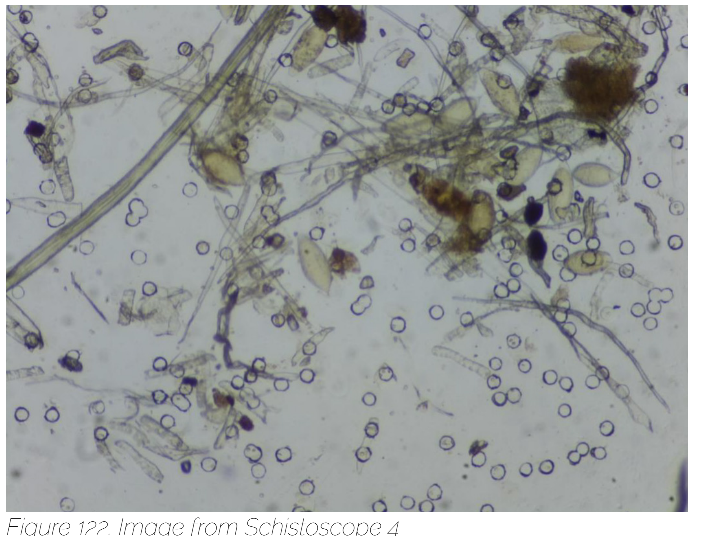

Figure 122. Image from Schistoscope 4

Figure 123. Image from Schistoscope 5

Evaluation on costs

Observation

The material costs of the Schistoscope 5 were an estimated €600. Experts perceived this as promising, with room for improvement. One fifth, €120, of the total price was used to acquire the aluminium frame.

Consideration

The Schistoscope 5 is an elaborate, digital microscope. However, it is difficult at this stage to compare the cost price to the market price of a standard microscope. Firstly, because the Schistoscope is capable of automated scanning, focus and can capture images. This is not comparable to a manual microscope. Additionally, the Schistoscope can save health care institutions on personnel costs, since a diagnosis can be performed by a cheaper, less educated employees, compared to the expensive, highly educated microscopist.

The financial side of the device should be one of the focus areas for the next iteration. Research into market value must be executed and a business model must be created.

Additionally, the current design brings stability to the Schistoscope 5 by integrating an aluminium frame, which is required to support the research towards a solution that will improve and save human lives. However, aluminium is a high impact material since it is a scarce natural resource with a polluting production process. Next iterations must aim to reduce the amount of aluminium used, while preserving the required stability.

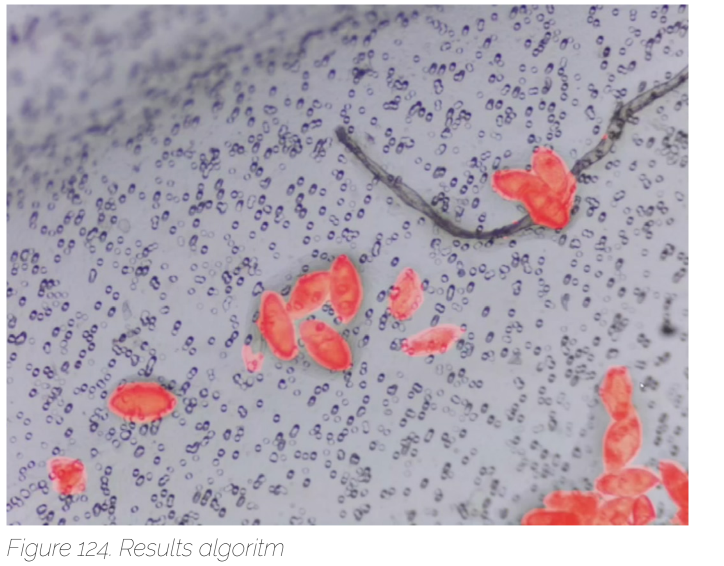

Figure 124. Results algoritm

Conclusion on sub-goals

Goal 1: Effectively captured qualitative images

The Schistoscope 5 needs to effectively capture qualitative images to ensure that the AI provides reliable results. The quality of the images from the Schistoscope 5 should be close to the quality of the images captured by the Schistoscope 4, because the AI is trained on a dataset of images from the Schistoscope 4. However, as explained in chapter Evaluation on quality, even more important is ensuring consistent quality. To achieve this goal, two challenges were defined.

Challenge 1: Improve the stability and fixation of the camera.

To effectively capture qualitative images, the device must provide a stable imaging set-up. The camera must be fixated, and the camera movement must be stable and reliable. The design increased the use off-the-shelf components to improve this stability. The extension tubes have C-mount screw thread, allowing the camera to be screwed onto the tube, creating a fixed connection. Vibrations from moving the optical system will not affect the position of the camera attached to these tubes, like the magnets did in the Schistoscope 4.

The off-the-shelf motorised linear guiding systems provide a stable and reliable movement. Because of the stability, vibrations are reduced. Therefore, the camera movement is more precise. Comparing the image preview of the Schistoscope 5 with the image preview of the Schistoscope 4 shows a clear improvement. There is no visible displacement in the image preview of the image sensor when moving up and down in the z-direction. This proofs the improved stability and fixation of the camera.

Conclusion: challenge 1 is completed

Challenge 2: Include illumination unit into the optical system

For the camera to capture an image, a light beam must be directed from underneath the sample onto the camera sensor. The design of an illumination unit was provided and included into the optical system. The given design of the illumination unit appeared ineffective in providing the required illumination to create a qualitative image. A new design was provided and integrated in the optical system. This new design provided the required illumination and contributed to the image quality.

Conclusion: challenge 2 is completed

Figure 123 shows a captured image from the final set-up of the Schistoscope 5 compared to an image captured by the Schistoscope 4, figure 122. Even though the quality differs, the AI is able to provide egg detection. Figure 124 shows the results of the algorithm.

Conclusion: Goal 1: Effectively captured qualitative images is achieve

Goal 2: Entire sample captured

This goal is set to ensure that the AI provides a complete egg count. Therefore, the Schistoscope 5 is set out to capture the entire sample, capturing all eggs. To achieve this goal, two challenges are defined.

Challenge 3: Allow for different Field of View

The sample moving system allows for a change of position of the sample slide relative to the optical system, thereby creating different FoVs to be captured by the camera sensor. The sliders used in the Schistoscope 5 allow for the required step size and automated change of FoV.

Conclusion: challenge 3 is completed

Challenge 4: Ensure consistent field of view

Inconsistencies in the Schistoscope 4 are due to a lack of precision in the automated linear sample movement and the glass slide being able to change position. In the Schistoscope 5, the sample moving system is much more reliable and accurate than in the Schistoscope 4.
However, the glass slide is not fixated onto the sample holder. As discussed before, this can cause for a change in position of the glass slide. However, the displacement only occurs when external influences create vibrations in the device. Even though the current design cannot guarantee consistent FoV, the challenge is at a sufficiently level of achievement.

Conclusion: challenge 4 is not completed but sufficient

Conclusion goal 2: Entire sample captured is achieved sufficiently

Goal 3: One integrated robust prototype

The Schistoscope 5 will be transported to a Nigerian laboratory and potentially to different locations in Nigeria. Therefore, it is important that the device is an integrated robust device. To achieve this goal, two challenges were defined.

Challenge 5: Provide stability of all systems inside the device

The device will automatically scan samples and one scan takes about 20 minutes to complete. Any interruption will only be noticeable after the scan is completed and viewed by the user. To minimize the number of interruptions as possible, all systems should be stable. Aluminium profiles create a rigid and stable frame that provides this stability. All other systems are easily attached to the frame and the frame is consistent and stable.

Conclusion: challenge 5 is completed

Challenge 6: Create a barrier between the systems and the environment

All Schistoscope systems should be integrated into an enclosure that serves as a barrier between the device, its internal systems inside and the environment outside. The current design of the enclosure system creates this required barrier and protects against the majority of dust, sand, airflow and water. Even though the enclosure is not completely sealed, it will protect the components inside under normal conditions.

Conclusion: challenge 6 is completed

The enclosure and supporting systems make the device into one integrated prototype. The rigid supporting system provides stability and robustness and together with the enclosure system the device is protected and perceived as one integrated device.
The device has been successfully transported throughout the project and in the final transport to Nigeria. Furthermore, the device is immediately ready to operate after transportation. Because of the supporting and enclosure systems, no damage occurred during transport.

Conclusion goal 3: One integrated robust prototype is achieved

Conclusion on main goal

The overall goal of this graduation project is to provide the research group with the Schistoscope 5, to support a field-test in Nigeria. This is achieved by providing three devices, based on the design presented in this thesis. Two of these devices are successfully transported to Nigeria and operational in the local laboratory (see figure 125).

The main goal of the Schistoscope 5 is to effectively capture a sample. By completing five challenges entirely and one challenge sufficiently, the three sub-goals are achieved. The images captured by the Schistoscope 5 have the required quality for the AI to execute diagnostic test on the samples. The Schistoscope is able to capture qualitative images of an entire sample as one integrated device. Thus, to conclude, the Schistoscope 5 has achieved the main goal.

Figure 125. Two operative Schistoscopes in Nigeria, 2021

Recommendations

In scenario 1, the Schistoscope is to be placed in medical institutions and laboratories to assist work performed by medical health practitioners on diagnosing Schistosomiasis. A production series of 10 devices can put the Schistoscope in facilities throughout Nigeria. It is assumed that the device will be stationary in these facilities and laboratories, which have similar conditions as the current field-test setting.

In scenario 2, the device can grow to a production series of approximately 100 devices. These devices are used in Mass Drug Administration (MDA) Programmes. MDA program excursions can take multiple days of traveling to rural areas without connection to the main AC power grid. Furthermore, the operators of this device does not require to analyse the data in the field. Feedback about adequately captured data and results if sufficient. The organisations will give out drugs based on previous endemicity test results. The data gathered from the Schistoscope will help gain insights in the spread of the Schistoscope endemicity and help target the populations for the next MDA programmes.

Scenario 3 addresses the last mile health carrier and local health care facilities. For this scenario, the production series can grow even higher. The health carriers are traveling to communities inaccessible for cars and bikes and bring health care to the people in need. Schistosomiasis is a poverty related disease and especially inhabitants of these isolated communities require treatment for Schistosomiasis.

Scenario 1

Maintain position of glass slide

Challenge 4 is not completely. Therefore, it is recommended is to research possibilities to maintain position of the glass slide in the device during a scan. The results will become more reliable and the chance on errors will decrease.

While creating a solution for this challenge, it should be considered to include changing the design of the sample holder and the sample stage. More about this in recommendation Sample stage. This will evidently influence the best solution of ensuring the positions of the slide. One suggested solution is to fixate the glass slide on the sample holder. Preferably a solution that does not require additional user actions is found. The users must trust the solution and be comfortable to use it.

Integrated display

The next iteration must integrate a touch screen display or a display and integrated keyboard to operate the device. Implementation of a touchscreen is recommended, since this will allow use of the device anywhere, without requiring additional accessories. However, the device must still include the possibility to attach an external mouse, keyboard and an external screen, to increase useability and co-operation. Especially the option to use an external screen will increase collaboration between users. Using a bigger extension screen will allow for multiple users to watch the same screen simultaneously.

Additionally, more attention to the user interface is essential when scaling the design towards a larger production. The user should be restricted to get inside the coding platform. Currently, users and developers are in the same operating system and no files or programmes are blocked for the user. It is recommended that the user can only enter an application or part of the operating system, in order to operate the device and run the diagnostics.

Research into acceptable displays, with regards to size, price, durability, and orientations, should be executed and system requirements must be set. The possibility of adjusting the angle of the screen must be considered. It will allow the user to put the screen in the desired position, however, moving components are prone to break.

Sample stage

Decrease placement errors

Additional research into implementation of use cues on sample placement must be executed. Ultimately, users must be guided in the process of placing a sample or providing the device with a sample in order to decrease placement errors. A possible placement error is when the sample is placed wrongfully on the sample holder, either slanted, unstable or so close to the edge the sample might fall during a scan.

Higher precision

Additionally, design iterations about the shape and materials of the sample stage must be considered. The current design provides a levelled sample holder which is sufficient to the current requirements. If multiple diseases or diagnostics methods in the future are implemented in the device, a higher magnification and thus a high level of precision is required in all systems, including the sample moving system. Preferably, a solution less prone to deflection is created. For example, a design that supports the sample stage at all corners to prevent deflection.

Sample placement

Iterations on the methods of providing the device with glass slides must be made. A possible solution can use similar principles as a CD-player tray. These trays are automatically moved in and outside the device. A user places the CD, or in the Schistoscope, a glass slide into a fitted notch or holder. The tray moves automatically to the required position in the device. The tray must allow for several sizes glass slides and provides the possibility of including a design for batch scanning, where multiple glass slides are processed simultaneously by the device.

Tube clamp

The current tube clamp satisfies the current quality requirements. However, the material properties of the 3D-printed clamp will eventually limit the level of precision. Over time, the force of the clamp might weaken and change alignment of the system, making the optical system unreliable.

Additional research into a z-movement set-up must be executed. Either a customised linear guiding system that includes camera and microscope objective or a customised clamp that will remain reliable over time should be considered.

Glass slide size

The Schistoscope 5 allows for the use of the common glass slide of size 26x76mm. However, there are more sizes available and, in some countries, or areas, not all sizes are commonly available. Therefore, the next iteration should design for the use of all different available sizes. This will increase the possibility of use. It will also increase the possibility for the use of a different size filter. In the field test the research group will use a 13mm round filter. However, 25mm is also commonly used and easier to use with a larger glass slide.

Furthermore, allowing for different sizes will also allow for diagnosing different diseases or diagnostic methods in the future. For example, Schistosomiasis Mansoni is diagnosed via stool samples, which are commonly prepared on larger sample slides.

Embodiment

Additional research into user perception of product embodiments must be executed. Field research in Africa can gather information about typical medical products, how colours are perceived throughout African countries and how to design a product that will be accepted in local communities.

The team must also consider producing the parts locally or provide a complete package that can be assembled locally. This will have impact on production methods and thus design of the embodiment.

The next Schistoscope must reduce the amount of aluminium. First, because of the contribution in total costs price of the Schistoscope 5. Furthermore because of the environmental impact of aluminium. A solution that provides the same stability but with a lower impact and price must be created. In addition, decreasing the amount of aluminium can create possibilities for aesthetic embodiment design, allowing for more organic free shapes.

Algorithm included

For the next Schistoscope, it is recommended to include a computer device, like a Jetson Nano, that can operate the device and run the algorithm for detection. This also includes updating the camera to a camera that corresponds with the chosen computer device.

Preferably, the operating system of this computer device allows for the use of applications or has the possibility to block the users access to the coding platform. Additionally, it is recommended to include an updated algorithm to detect multiple species of Schistosomiasis.

Power usage

The current Schistoscope requires AC power input and has no back-up power to intercept power outages. One insight gathered from the field test, is that the main power grid in Nigeria is not reliable. During the field test, the team used power generators, however, those also appeared less reliable than anticipated.

For the next iteration, it is recommended to include a battery that can save enough energy for one complete scan. In the case of a power outage, the battery can ensure that current scan is completed. Considerations regarding durability, weight and sustainability must be researched.

Production

The Schistoscope project must diverge from the use of 3D-printing as one of the main production methods. The device requires microscopic precision, which most commercially available 3D-printers cannot deliver. Therefore, 3D-printing is not considered a suitable method. 3D-printing should predominantly be considered as specialised for small parts that do not require high precision.

Scenario 2: MDA programmes

1. Batch scanning

The device must have a higher throughput to affectively screen the population. Therefore, scanning a batch of samples must be possible with the new device. For example, using a sample tray to place multiple glass slides and scan the samples simultaneously or have a continuous throughput of samples. Perhaps a glass slide feeding unit must be included to create a nonstop flow of samples.

Additionally, research into identifying sample IDs and administration should be conducted. Possibilities of scanning written ID numbers, or added codes such as QR- or barcodes, should be considered. Using unique glass slides designed for the Schistoscope could include features for the device to recognize, identify and match the ID to the captured images.

2. Power supply

This scenario requires either including a battery large enough to save energy to be operative for multiple days or include possibility of generating power within the device itself. For example, including solar panels to charge the internal battery while running diagnostics in the field.

3. User interface

Operation of the device for this scenario should be easy and as efficient as possible. This could entail only integrated the required buttons to operate the device and include a Schistoscope application. In this application, users can operate multiple devices, review the results and be updated when a scan is completed. Data about location and population can be entered via the application and administration and documentation of the MDA can be included. A smartphone has a GPS integrated, which allows for easy access to location data.

4. Portable

It is assumed that during the MDA programme, the users will rely on cars and occasionally a motorbike. Therefore, the device must be transportable by car, easily picked-up and put aside. It is not required to walk long-distances while carrying the device, however, the design must exceed all unnecessary weight.

5. Local maintenance

Because the device will be traveling with the MDA program, maintenance should be possible and easy. The device must use regular fixtures. Important parts like camera and objective must be accessible for maintenance and repair.

6. Include more diseases

It is considered efficient if the device will include more diseases than Schistosomiasis. In collaboration with the MDA organisations, other target diseases must be integrated in the device. This will create a more diverse and complete profile of the population the MDAs are targeting. However, by including more diseases, the project must reconsider the name 'Schistoscope', and possibly change it to a more inclusive name.

Scenario 3: Last mile health carrier

1. Power

In the health care facilities or rural communities, there often is no main power grid. The device must be completely self-sufficient in energy supply. With the current available technologies, solar power is considered a fitting solution and must be integrated in the device for this scenario.

2. Mapping areas

In this scenario, the users might want to keep track on the communities by adding location information with the scan results. The devices need to track the location with an integrated GPS inside the device. This will help map-out the infections and create insights for the healthcare giver in to the endemicity of certain areas. This can be used for targeting MDA's or other development projects.

3. User interface

For this device, either a display or a connected smartphone must operate the device. Including a display in the device will limit the need for external devices in order to operate the device. However, on a smartphone or tablet, the results are easily carried to other locations and are shared with health care facilities or organisations.

4. Portable

This scenario has a high need for portability. Healthcare carries traveling to the most rural areas, where cars and bikes cannot come. Every additional luggage needs to be necessary. Therefore, the device must be as small and light as possible and easy to bring along while traveling on foot.
Preferably, all tools to prepare samples are included in the transportable device, either integrated into a bag that can hold the device, or the device allows for storage of glass slides, syringes and filter, etc. The device must be robust and withstand impacts that arise during such journeys.

5. Integrated AI

For this last stage of the device, the electronics included must be integrated into one complete custom PCB. No use of Raspberry Pi or Jetson Nano, which contain features that the device does not require. A development for a PCB that contains all the required electronics and can fit in to the design is necessary.

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5 Appendix

Figure 122. Field test Nigeria, 2021

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Braakman 4861
initials: I.G. given name: Ingeborg
student number: 4477650
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ★ IPD / DfI / SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: J.C. Diehl — dept. / section: SDE/DfS
** mentor: J. Trappenburg — dept. / section: SDE/DfS
2nd mentor:
organisation:
city: country:

comments (optional): Members from the same section because the chair provides expertise on project and context and the mentor provides expertise on embodiment.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair: J.C. Diehl — date: 14 - 03 - 2021 — signature: jdiehl (Digitally signed by jdiehl Date: 2021.03.23 13:16:01 +01'00')

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 27 EC

Of which, taking the conditional requirements into account, can be part of the exam programme: 27 EC

List of electives obtained before the third semester without approval of the BoE

★ YES — all 1st year master courses passed

NO — missing 1st year master courses are:

name: C. van der Bunt — date: 26 - 03 - 2021 — signature: C. van der Bunt (Digitally signed by C. van der Bunt Date: 2021.03.26 11:37:37 +01'00')

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED / NOT APPROVED

Procedure: ★ APPROVED / NOT APPROVED

remarks:
- planning is too long, should be 100 days
- typo in title a should be an optical

comments

name: Monique von Morgen — date: 12 - 04 - 2021 — signature:

Initials & Name: I.G. Braakman 4861 — Student number: 4477650

Title of Project: Improving an optical diagnostics device for Schistosomiasis

Improving an optical diagnostics device for Schistosomiasis project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 22 - 02 - 2021 16 - 08 - 2021 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Schistosomiasis is a Neglected Tropical Disease, prevailing mostly in poor and rural communities in sub-Saharan Africa, particularly those that heavily rely on water bound occupations, such as fishing and specific agriculture. In 2019, a total of 236.6 million people required treatment for schistosomiasis and only 1 million received it. Schistosomiasis is a chronic parasitic disease caused by blood flukes that infiltrate human skin when in contact with contaminated water. The parasites travel through blood vessels to intestines and bladder of the host, where male and female parasites pair up and lay eggs. Some eggs will continue to contaminate water when released in faeces or urine. Other eggs are trapped in body tissues, causing immune reactions and progressive damage to organs.

The body's reaction to the Schistosoma eggs varies per species and with stage of infection. Untreated, infection intensity increases, and more complications arise e.g., fibrosis of the bladder and ureter, kidney damage and bladder cancer. In children, the disease can also cause anaemia, growth retardation and a reduced ability to learn. The disease also has long-term irreversible consequences affecting people's ability to work and can result in death. Early treatment is key in reducing long term morbidity and preventing chronic infections. In endemic areas, praziquantel (preventive chemotherapy) treatment programmes are used periodically. Either aimed at school-aged children, adults considered to be at risk or entire communities. The frequency of treatment is determined by the prevalence of infection in school-age children.

Schistosomiasis is currently diagnosed through the detection of parasite eggs in stool or urine specimens. Eggs are detected and counted by a trained microscopist examining the filter on a glass slide. To prescribe the correct amount of praziquantel, the number of eggs in 10ml urine is counted to determine the intensity of contamination and prescribe related dosage. Accurate diagnosis is crucial to reduce risks of chronic infections.

Stakeholders within the NWO INSPIRED Project:
- Client: dr. ir. J.C. Diehl, leader of Delft Global Initiative's research group Diagnostics for All. They address challenges that are urgent in low-resource countries but relevant worldwide by using their expertise to find concrete and sustainable solutions that directly improve lives of people living in poverty, in close cooperation with local partners.
- Experts included in INSPiRED, a collaborative project of Leiden University Medical Center, Delft University of Technology, University of Ibadan (Nigeria) University of Lagos (Nigeria) and CERMEL (Gabon). INSPiRED is a research project for development and validation of inclusive, smart, easy to use, cost effective and efficient optical devices for the diagnosis of poverty related parasitic diseases in Nigeria and Gabon. They want to reduce the burden of these diseases by conducting laboratory and field validation of their developed devices, and to engage stakeholders for the uptake of these devices in the healthcare systems.
  - o Ir. Satyaith Jujjavarapu: developer of algorithm and current technical prototype
  - o Dr. Temitope Agbana: context expert
  - o Meulah Brice: Microscope expert
  - o ir. Prosper Oyibo: Aritificial Inetlligence expert?
- Student. I will work together with experts from INSPiRED and Diagnostics for All towards a new diagnostic device for schistosomiasis.
- Intermediate user: To goal of my project is to develop a device that will be used by the experts included in INSPiRED. They have different needs and values then the envisioned user, e.g., Community Health Workers. My project will focus on this intermediate user, but I will keep the envisioned user in mind.

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: User context in Nigeria laboratory

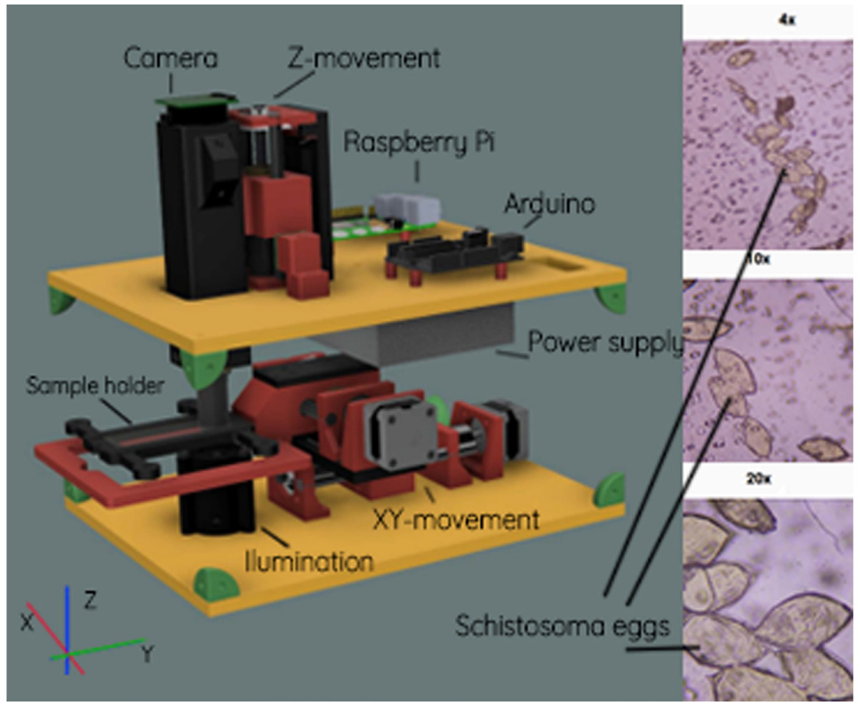


image / figure 2: Current prototype with results

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Millions of people are still infected with Schistosomiasis and in need of treatment. Without treatment people are vulnerable for chronic infections and eventually death. The current diagnostic method is standard microscopy. This is difficult and hard work, requiring a non-ergonomic posture and medical training. Only a limited group of people can properly receive this training, due to a lack of resources for education. As an alternatove the INSPIREDPorject has developed the Schistoscope to automate this process to replace the microscopist. They developed a proof of principle (see figure 1) but not yet a ready made embodied device for testing in real clinical settings.

Therefore, they need a design that proofs efficacy within the context of Nigeria. Currently they have a functional prototype of the Schistoscope, which is a purely technical set-up, focussing on reliability.
In June 2021, the research group plans to execute a large field study. The goal is to collect samples in highly infected communities and run test with the Schistoscope in a laboratory as shown in fig. 1. The current device is not sufficient for executing this test. It needs improvement.

Clear areas of improvement are: The moving components need to be stabilized to repeatedly capture decent pictures. There has been no attention to usability and ergonomics. The way the operator places the sample in the device could be improved. Likewise, the current device does not have a proper embodiment, or ways for heat dissipation. Furthermore, several components should be accessible for repair or replacement. Other components should be accessible for maintenance, for example, cleaning the lenses of the microscope.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I will improve the current Schistoscope to a level that can execute a large field study early June. 2021 in Nigeria
This improvement entails stabilizing the moving components and adding a proper embodiment.
Additionally, research and apply user- and ergonomic-needs and design for repair and maintenance.

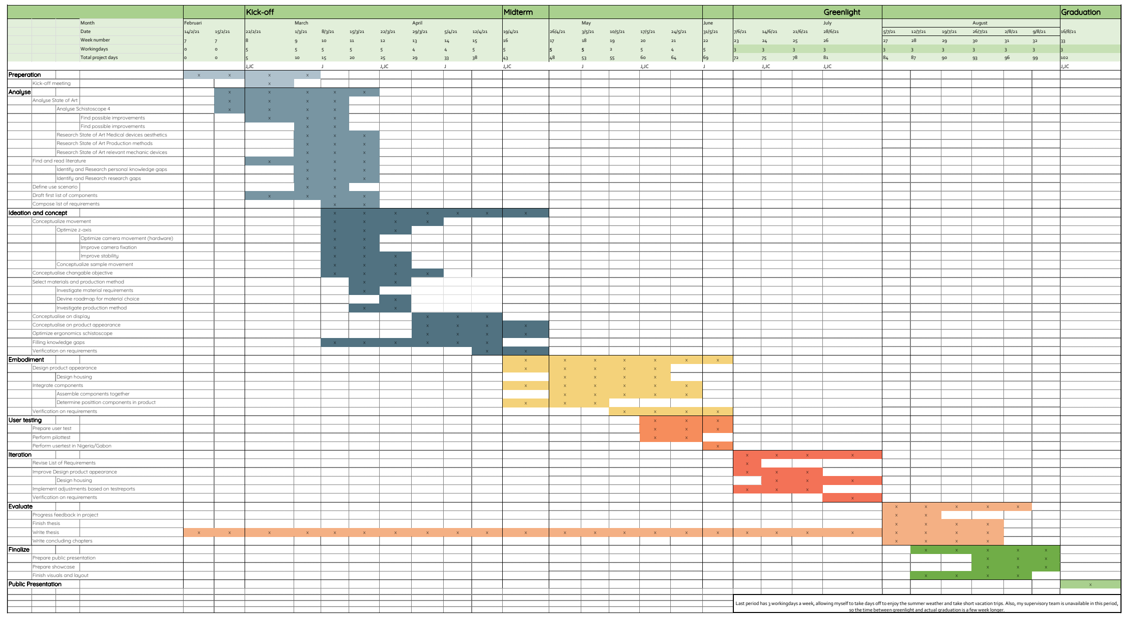
I expect to deliver a product that satisfies the needs of the user and is an improvement of the current device. The focus lies with reliability and functionality. However, I will include investigating usability, ergonomics and aesthetics. I aim to have a functional prototype ready early June for the field test. Additional aesthetics can be designed during the field test.
To reach my goal I will investigate the following aspects/areas for improvement:
- Enhanced stability
  - o Stabilize z-axis.
  - o Stabilize camera.
  - o Stabilize embodiment.
- User friendly sample placement
- Design for Maintenance
  - o Cleaning lenses
  - o Change lenses.
- Design for Repairability

Not required thus optionally
- Improve power supply by integrating a PCB design that transforms the input to required output for the components.
- Design for heat dissipation

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 22 - 2 - 2021 16 - 8 - 2021 end date



Note: This Ghant-chart is a shortened version, with less detailed steps than the original chart.

It can be seen in the planning that the first design phases are described in more detail than the final phases. My assignment requires a prototype late May. My goal is to have a prototype ready for about 75%, which means functionally ready with room for improvements on aesthetics and user friendliness. Depending on the obtained insights in the first phases I might add or remove other activities in this planning.

The planning of the field study is difficult to specify at this point. This is due to the current uncertainties surrounding the execution of this phase. Right now, it is expected to be late May early June. As I intend to finish this project before the beginning of the new academic year I did not plan any holidays or parallel activities before the Greenlight. I did plan for 9 delay before the Greenlight. There are six weeks planned between the Greenlight meeting and Graduation Day because of vacation days from committee (from 3/7/21 until 13/8/21). I can use these days as a buffer and if suitable a short vacation.

Last period has 3 workingdays a week, allowing myself to take days off to enjoy the summer weather and take short vacation trips. Also, my supervisory team is unavailable in this period, so the time between greenlight and actual graduation is a few week longer.

MOTIVATION AND PERSONAL AMBITIONS
Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Why?
I was part of the Schistoscope project for my master's course AED in 2020. This was my first contact with both project and dr. ir. J.C. Diehl. I was amazed by the enthusiasm and involvement of him and his team. I realized that I find motivation in a valuable project that includes challenging complexity and creates impact. During AED, I was intimidated by the complexity of the disease. Its vicious circle requires not only medical treatment to eliminate the disease, but also technical advancements. Therefore, every step counts. A well-designed device provides patients with better treatment to prevent chronic infections and deaths. Furthermore, governments can target elimination measures to the areas where effect will be big. I want to contribute to something valuable and work on a desired solution to a significant problem. I see a challenge in the technical complexity and the need to design for a specific context. I appreciate the existing connection with the people in the medical field and the people located in Africa.

What I know and can apply
Last summer, I did an internship with TU Delft that taught me new prototyping techniques. Additionally, I learned that a project with no clear goal is difficult to manage and challenging to keep motivated by. Applying this insight, it is important to determine the scope, goal and result of my graduation. Because of AED, I have an advantage because I have prior knowledge about some challenges and opportunities relevant in this project. I partially contributed to Design for Scalability, Low Cost and Local Production. Additionally, I know which parts of the project will suit me and for which parts I need more time. Furthermore, initial contact with some of the experts will be easier because of the previous contact. Practically, I have learned that external manufacturers are often open-minded and available for expertise. Plus, I have little experience in coding, which will help me to communicate with experts. Furthermore, I am educated with basic sustainability approaches. I want to explore my abilities and limitations in this field.

What I want to learn
I want to expand my knowledge and skills in design for sustainability. My education provided a basic understanding and approaches. I want to learn how to reach and make a responsible decision. I want to create an understanding of design for sustainability in a complex context. I want to improve my knowledge and skills in Design for Scalability, Low Cost and Local Production. I want to learn how to create a balance between costs, functionality, local production and sustainability. Furthermore, I expect to increase my knowledge of coding and software. I should learn to control parts of the prototype and create an understanding of the provided software. I do not need to provide the final software but should have a fundamental understanding.

What I want to prove
I want to prove my work ethic. I can take on different roles; manager, producer, client, designer. I want to discover which roles fit me well and which challenge me. I want to prove that I can plan, manage and execute the total design process independently and co-operate in an international collaboration with stakeholders and experts. I want to prove my academic competence as an IPD student, balancing the needs of stakeholders and generating expertise based on research. Furthermore, I want to show my knowledge about aesthetic, ergonomic and technical issues and my expertise in integrating these issues into the development of products. At last, I want to prove my creativity and ability to create a meaningful, functional design. I will show that I have the qualities to create and validate concepts and the means to judge results.

FINAL COMMENTS
In case your project brief needs final comments, please add any information you think is relevant.

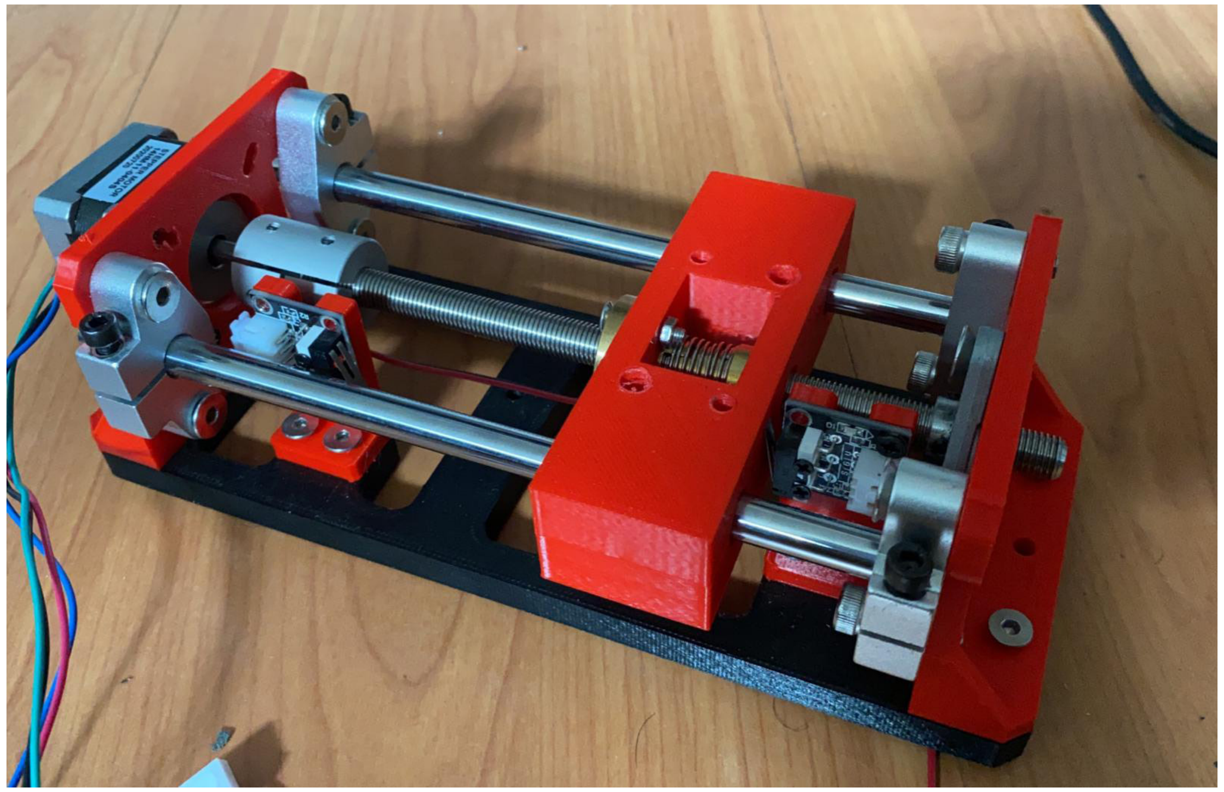
The ghant-chart is a shortened version, but still might be hard to read. All stakeholders will receive a separate pdf with the complete ghant-chart.

Initials & Name I.G. Braakman 4861 Student number 4477650

Title of Project Improving an optical diagnostics device for Schistosomiasis

B Estimated cost slider Schistoscope 4

Component	Estimated price
Stepper motor [16]	€9.10
Guide rod [29]	€4.60
Lead screw nut [23]	Included in lead screw
Lead screw [23]	€3.10
4 guide rod joints [13]	€6.20
1 lead screw joint [23]	€1.40
Rough estimate total	€24.40



C Estimated cost Schistoscope 5

1	**Electronical**	Item	Specification	Amount	*Section total:*	*€ 141,51*	
2	Off-the-shelf	Raspberry Pi		1	€ 90,00	€ 90,00	estimation
3	Bolts		M3	4			
4	Nuts		M3	4			
5	3D		Distance holders	4			
6	Off-the-shelf	5V 4A Power supply		1	*€ 0,57*	*€ 0,57*	
7	Off-the-shelf	USB F to USB M		3	€ 2,21	€ 6,64	
8	Bolts			6			
9	Nuts			6			
10	Off-the-shelf	HDMI F to HDMI Mini M		1	*0,4*	0,4	estimation
11	Bolts			2			
12	Nuts			2			
13	Off-the-shelf	Ethernet F to Ethernet M		1	*€ 3,76*	*€ 3,76*	
14	Bolts			2			
15	Nuts			2			
16	Off-the-shelf	USB to USB-micro		1	*0,4*	*0,4*	estimation
17		Custom PCB		1		*€ 0,00*	
18	Bolts		M3	4			
19	Nuts		M3	4			
20	3D		Distance holders	4			
21	Off-the-shelf		Pico	1	*€ 10,00*	*€ 10,00*	estimation
22	Off-the-shelf	Dual Output SMPS		1	€ 25,10	€ 25,10	
23	Bolts		M2.5	3			
24	Off-the-shelf	Power socket		1	€ 0,92	€ 0,92	
25	Bolts						
26	Nuts						
27	Off-the-shelf	3 pin power cable		1	€ 3,14	€ 3,14	
28	Off-the-shelf	On/off switch		1	€ 0,58	€ 0,58	
30	**X-Y**				*Section total:*	*€ 83,85*	
31	Off-the-shelf	Y-slider		1	*€ 40,60*	*€ 40,60*	
32	3D		X to Y mounting plate	1			
33	Bolts		M3	4			
34	Thread inserts		M3	4			
35	Off-the-shelf	X-slider		1	*€ 39,25*	*€ 39,25*	
36	Bolts		M3	4			
37	3D		Sample stage	1			
38	Bolts		M3	4			
39	3D		Sample holder	1			
40	Bolts		M3	4			
41	Thread inserts		M3	4			
42	Off-the-shelf		Spring	4	*0,4*	*1,6*	estimation
43	Off-the-shelf					*€ 0,00*	
44	Thread inserts		M3	2			
45	Bolts		M3	2			
46	Off-the-shelf	Endswitch		6	*0,4*	*2,4*	estimation
47	3D		Endswitch mount X	2			
48	Cables		Endswitch	3			
49	Thread inserts		M2	4			
50	Bolts		M2	4			
51	3D		Endswitch mount Y	2			
52	Thread inserts		M2	4			
53	Cables		Endswitch	3			
54	Bolts		M2	4			

	Device total:		€ 592,92				
55	**Z**				*Section total:*	*€ 152,11*	
56	Off-the-shelf	Z-slider		1	*€ 39,25*	*€ 39,25*	
57	Bolts		M3	4			
58	3D	Z to frame mount		1			
59	Bolts		M4	2			
60	Slider nuts		M4	2			
61	3D	Clamp to slider mount		1			
62	Thread inserts		M3	4			
63	Bolts		M3	4			
64	3D	Tube clamp		1			
65	Bolts		M3	4			
66	Bolts		M4	2			
67	Nuts		M4	2			
68	Off-the-shelf		Pi Camera	1	*€ 60,00*	*€ 60,00*	estimation
69	Off-the-shelf		Camera cable	1			
70	Off-the-shelf		Extension tube	1	*35,01*	*35,01*	estimation
71	Off-the-shelf		C to RMS mount ring	1	*€8,85*	*€8,85*	
72	Off-the-shelf		4X Objective	1	*€ 9,00*	*€ 9,00*	
73	3D		Endswitch mount Z	2			
74	Thread inserts		M2	4			
75	Cables		Endswitch	3			
76	Bolts		M2	4			
77	**ILLUMINATION UNIT**				*Section total:*	*48,73*	
78	Off-the-shelf	Star LED		1	*0,4*	*0,4*	estimation
79	Cables		LED	2			
80	Bolts		M2.5	2			
81	Thread inserts		M2.5	2			
82	Off-the-shelf	Condenser lens		2	*€ 17,80*	*€ 35,60*	
83	Off-the-shelf		Thorlabs order fee	1	*€ 12,73*	*€ 12,73*	
84	3D	Illumination body		1			
85	3D		Seal	1			
86	3D		Top	1			
87	3D		Middle	1			
88	3D		Bottom	1			
89	Bolts		M4	3			
90	**Display**				*Section total:*	*0*	
91	Off-the-shelf	Full HD Display		1			
92	**Frame**				*Section total:*	*€ 119,95*	
93	Off-the-shelf	2040 Alu frame 1000mm		1	*€ 17,50*	*€ 17,50*	
94	Off-the-shelf		2040 Alu frame 300 mm	1			
95	Off-the-shelf	2020 Alu frame 1000mm		3	*€ 9,50*	*€ 28,50*	
96	Off-the-shelf		2020 Alu frame 300 mm	3			
97	Off-the-shelf		2020 Alu frame 200 mm	4			
98	Off-the-shelf		2020 Alu frame 215 mm	2			
99	Off-the-shelf		2020 Alu frame 350 mm	2			
100	Off-the-shelf		2020 Alu corner fasterners	16	*€ 3,75*	*€ 60,00*	
101	Off-the-shelf		Adjustable feet	4	*€ 2,25*	*€ 9,00*	
102	Off-the-shelf		123-3D order fee	1	*€ 4,95*	*€ 4,95*	
103	**Plates**				*Section total:*	*€ 46,77*	
104		Alu and polycarbonate window tot		1	*€ 46,77*	*€ 46,77*	

Medical aesthetics

Aesthetics

The purpose of this chapter is to gain insight into the aesthetic qualities of the Schistoscope 4.0 in a structured way. By systematically comparing the design to similar products and paying attention to aspects in which they perform better or worse on the aesthetic plain, easy improvement using only slight modifications can be found.

The chapter consists of two collections of ten products that belong to the same category as the Schistoscope, diagnostic devices and medical devices. The products are awarded a score (1-7) on the following criteria:

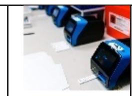
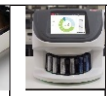
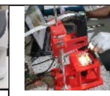
- Aesthetics (is it beautiful, attractive?)
- Unity (is it unified, does it strike you as a coherent whole?)
- Variety (are there many different elements, do the composing elements differ?)
- Typicality (is it a common design, do you easily recognize it as belonging to a particular product type or range?)
- Novelty (is it original, does it stand out compared to similar products?)
- Connectedness (does this product convey that its owner/user belongs to a group?)
- Autonomy (does this product allow its owner/user to stand out?)

To arrive at the needed improvements, the different scores on aspects are plotted against each other, to discover how the products perform on various positions on aesthetics and How the Schistoscope performs.

Diagnostic devices

Insight:

- Most of these products are **in vitro**
- Insert a stick into the front of the machine
- Read results on a screen, slightly angled
- More design interface

Score 1-7										
Aesthetics	7	7	5	4	7	5	2	3	7	1
Unity	7	7	4	4	7	7	1	2	7	3
Variety	4	3	6	6	2	6	7	7	1	3
Typicality	4	4	4	3	4	7	1	7	1	7
Novelty	6	3	1	5	6	5	7	1	7	1
Connectedness	1	4	4	3	6	4	1	7	2	7
Autonomy	7	7	4	7	7	5	7	1	7	1

Medical devices

Insight:

- Most products are in direct contact with patient
- White and black
- Boring, informative screens

Score 1-7										
Aesthetics	2	5	7	2	2	7	2	4	3	3
Unity	3	7	5	1	7	7	1	6	5	7
Variety	7	4	3	7	1	1	7	4	3	6
Typicality	7	5	4	7	2	5	1	2	3	1
Novelty	1	7	4	1	3	7	7	7	3	7
Connectedness	7	6	5	7	2	3	1	4	1	1
Autonomy	1	6	5	1	6	7	7	7	5	7

Conclusion

Of the products that score a 7 on aesthetics, the other aspect have an average of high unity, low variety, average typicality, average novelty, average connectedness and high autonomy. The Schistoscope 4.0 scores a Low unity, High variety, Low typicality, High novelty ,Low connectedness and High autonomy

	Average	Schistoscope 4.0	Difference
Aesthetics	7.00	2.00	5.00
Unity	6.67	1.00	5.67
Variety	2.33	7.00	4.67
Typicality	3.67	1.00	2.67
Novelty	5.50	7.00	1.50
Connectedness	3.50	1.00	2.50
Autonomy	6.67	7.00	0.33

Best improvements lie in

1. improving the unity.
2. decreasing the variety to a lower level
3. slightly Improving the typicality.

While adapting on these aspects, the other aspects should be taken into account, preferably improved as well..

Colours

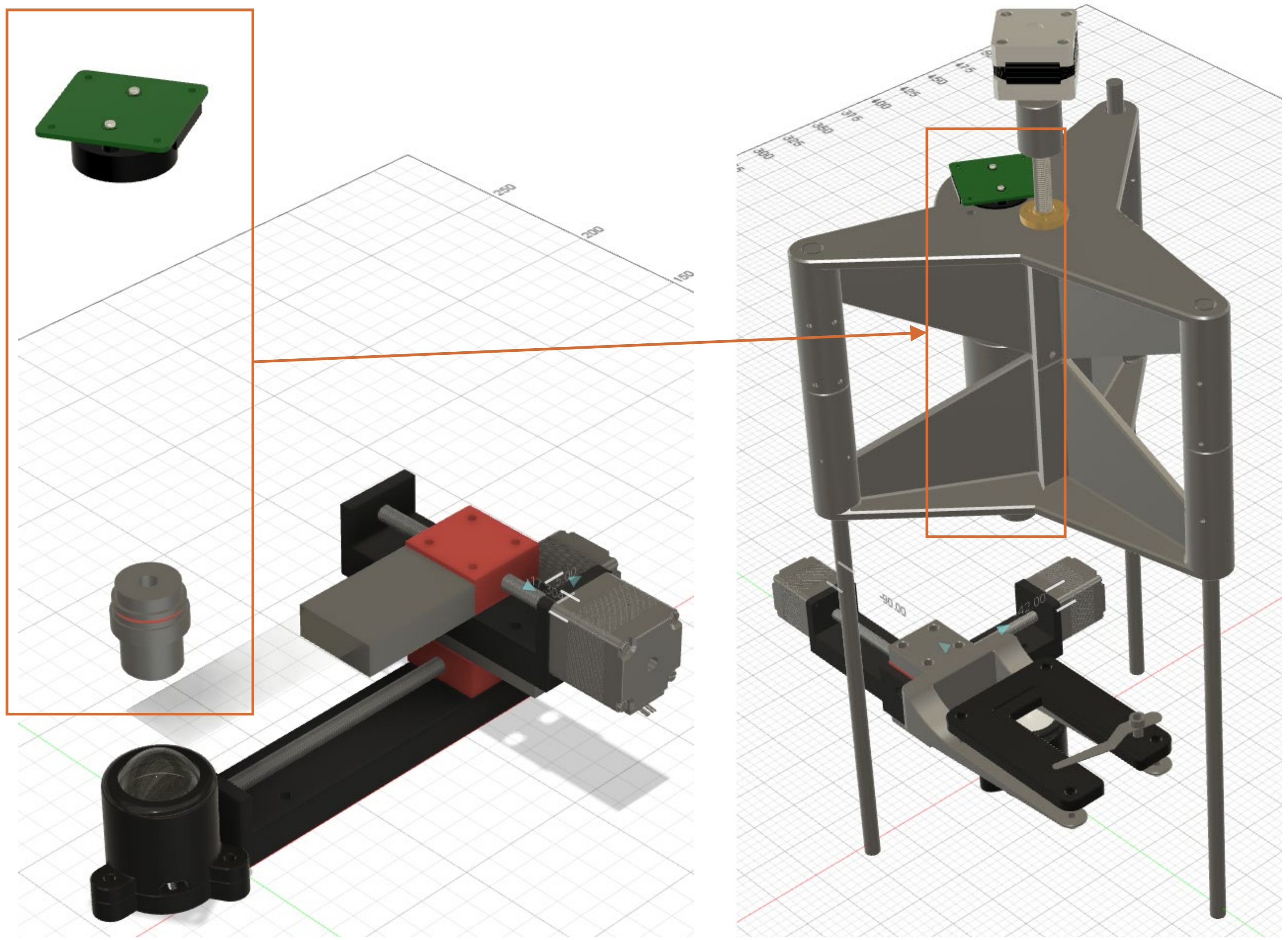
The search term 'medical device' on google provides an overview of images, which all have a blueish colour. In the figure below you see this is similar to other search engines.

Analysing the screenshot of the engine searches with an online programme provided several possible colour combinations extracted from the image

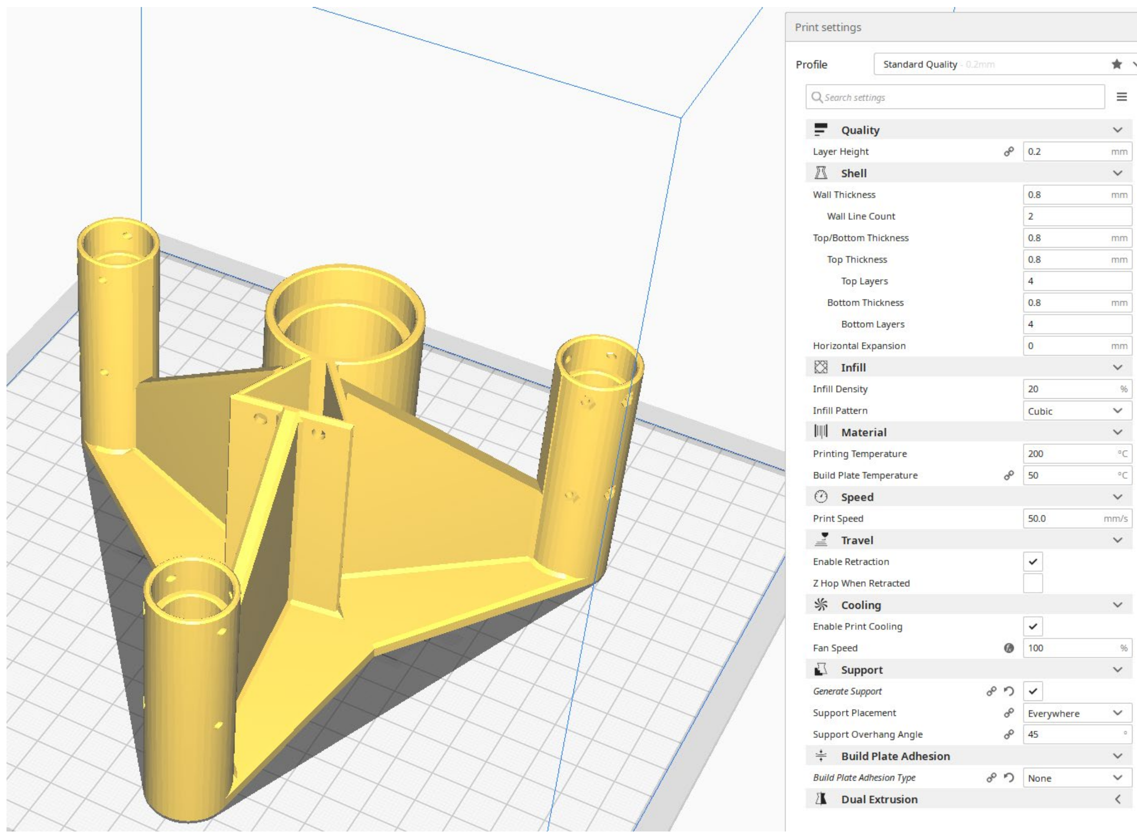
https://www.imgonline.com.ua/eng/get-dominant-colors-result.php

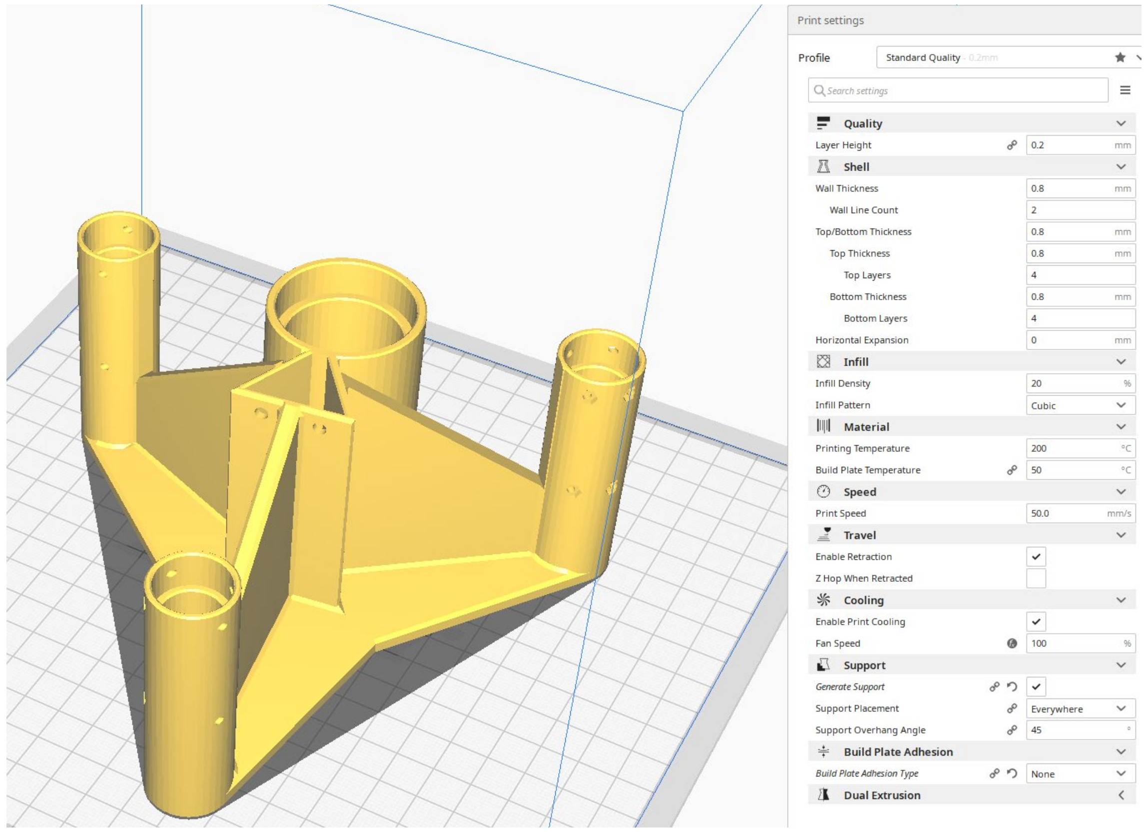
E Z-triangle problem visual

I have a camera and a microscope objective that need to be fixed at 160 mm from each other. Together, they should move up and down while keeping their x and y coordinates.



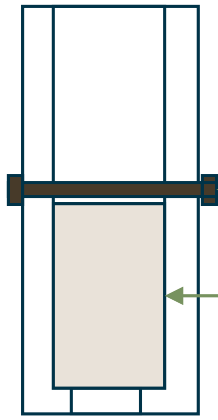
My design consists of two parts like the yellow part below.
Together they form the triangular object on the left.
This object is driven up and down by a motor and a lead screw and is lead by 3 guide rods to maintain x- and y-coordinates. The rods are fixated at both ends, thus rigid.





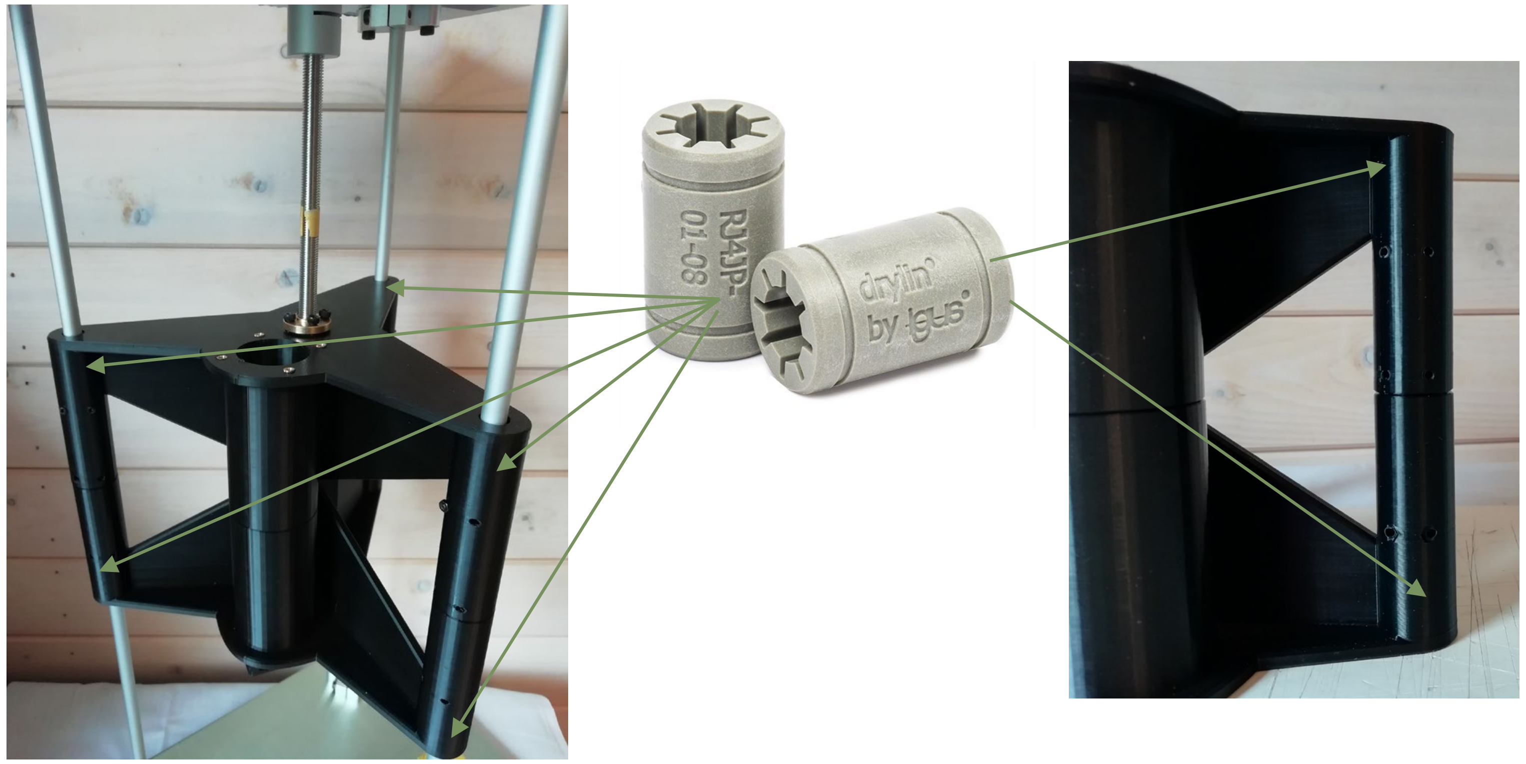
I have printed the yellow part twice.

I used 3 Igus drylin bearings inside each part, (in the three cylinders at the end, 6 in total) to guide the part along the rods with as little friction as possible. The bearings are not clamped but are hold in place with a nut and bolt, to prevent the bearing from sliding away.

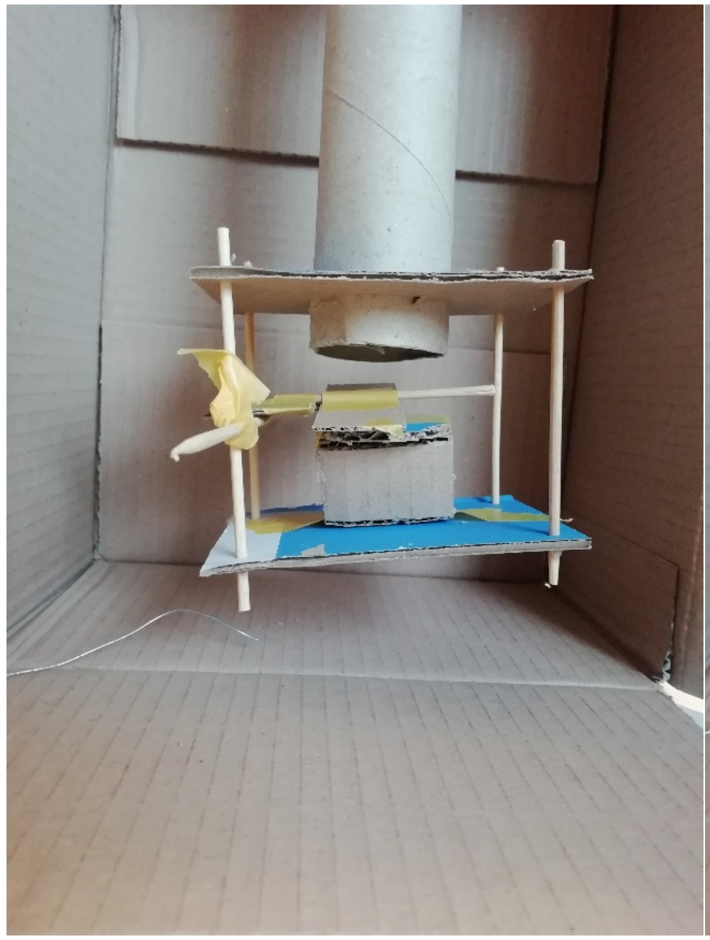


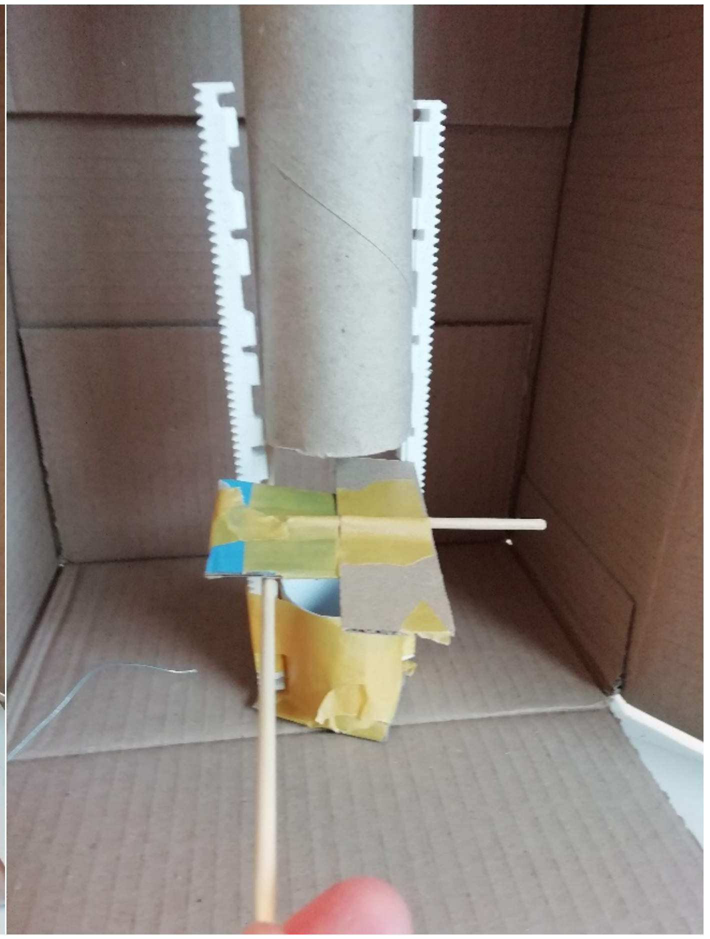
However, my print became crooked while being printed. Therefore, the bearings are tilted and not linear relative to each other. This causes too much friction on the guide rods.

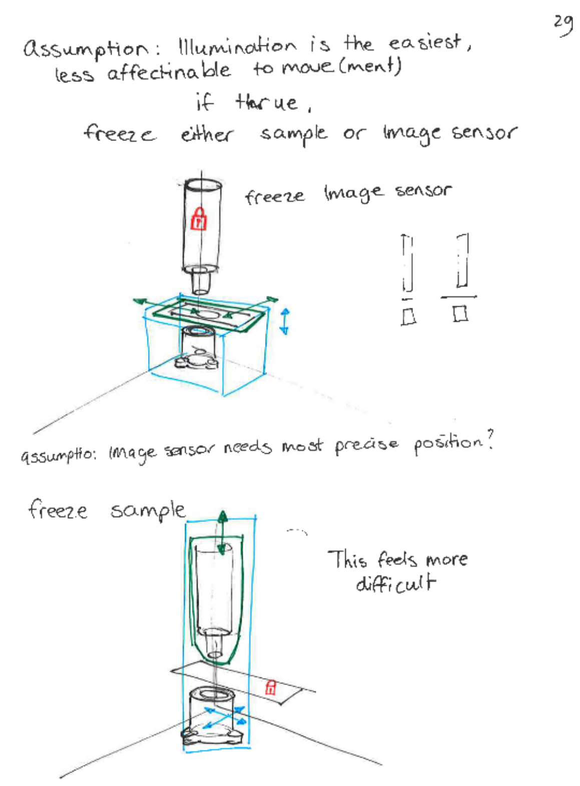
I could use:
- Tips to improve print quality
- Tips on a better design

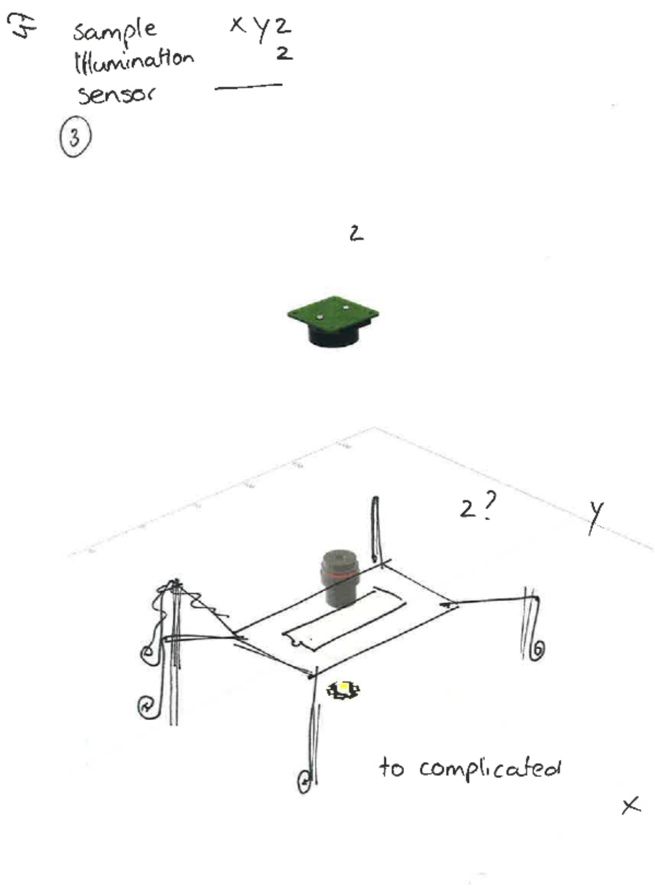


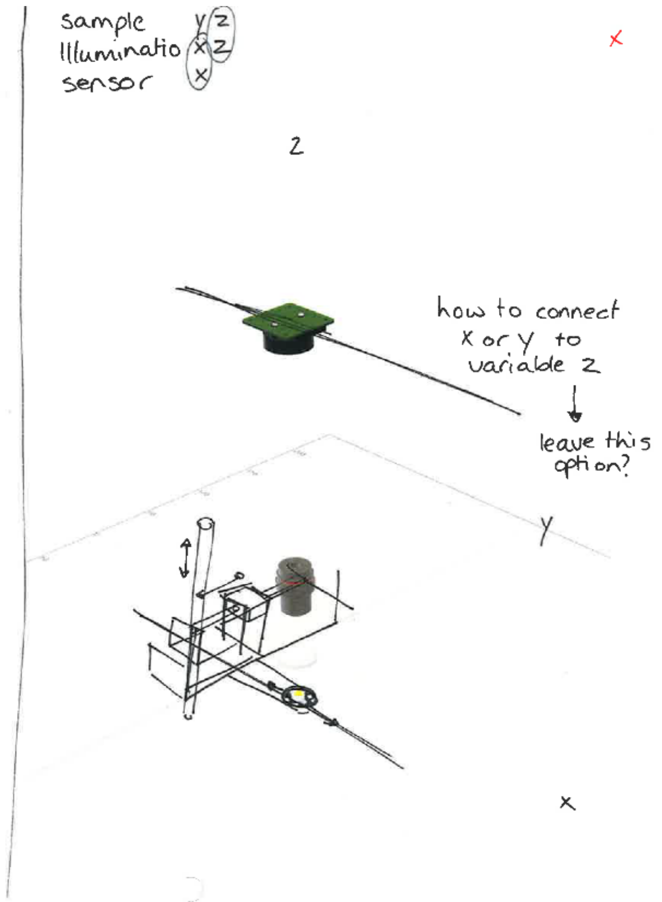
F Visuals on relative movements

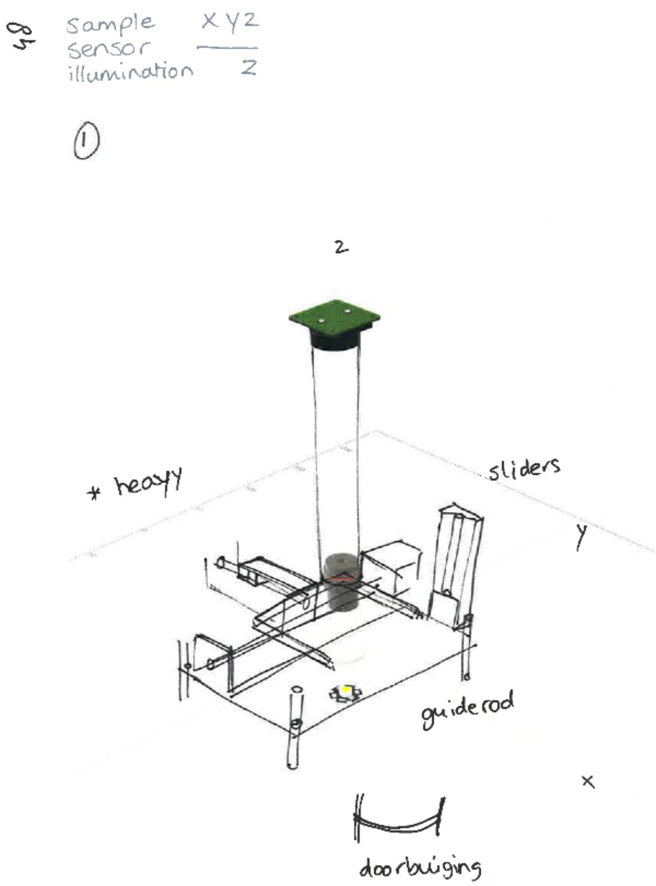





29
assumption: Illumination is the easiest, less affectinable to move(ment)
if the ue,
freeze either sample or image sensor
freeze image sensor
assumptio: image sensor needs most precise position?
freeze sample
This feels more difficult


sample xyz
Illumination z
sensor
3
z
z?
y
to complicated
x


sample
Illuminatio
sensor
z
how to connect x or y to variable z
leave this option?
y
x


sample xyz
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+ heavy
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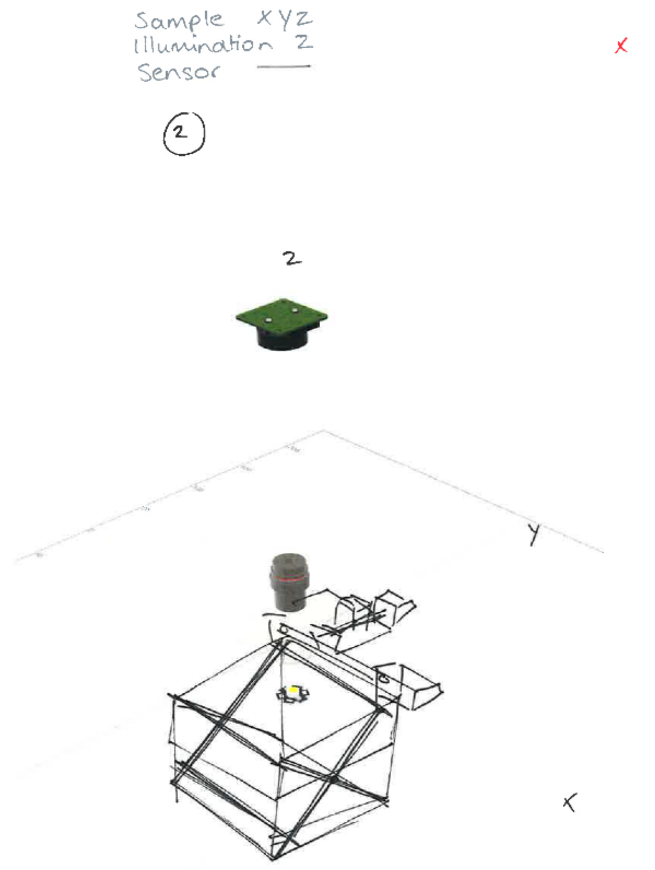
sample xyz
Illumination z
Sensor
2
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y
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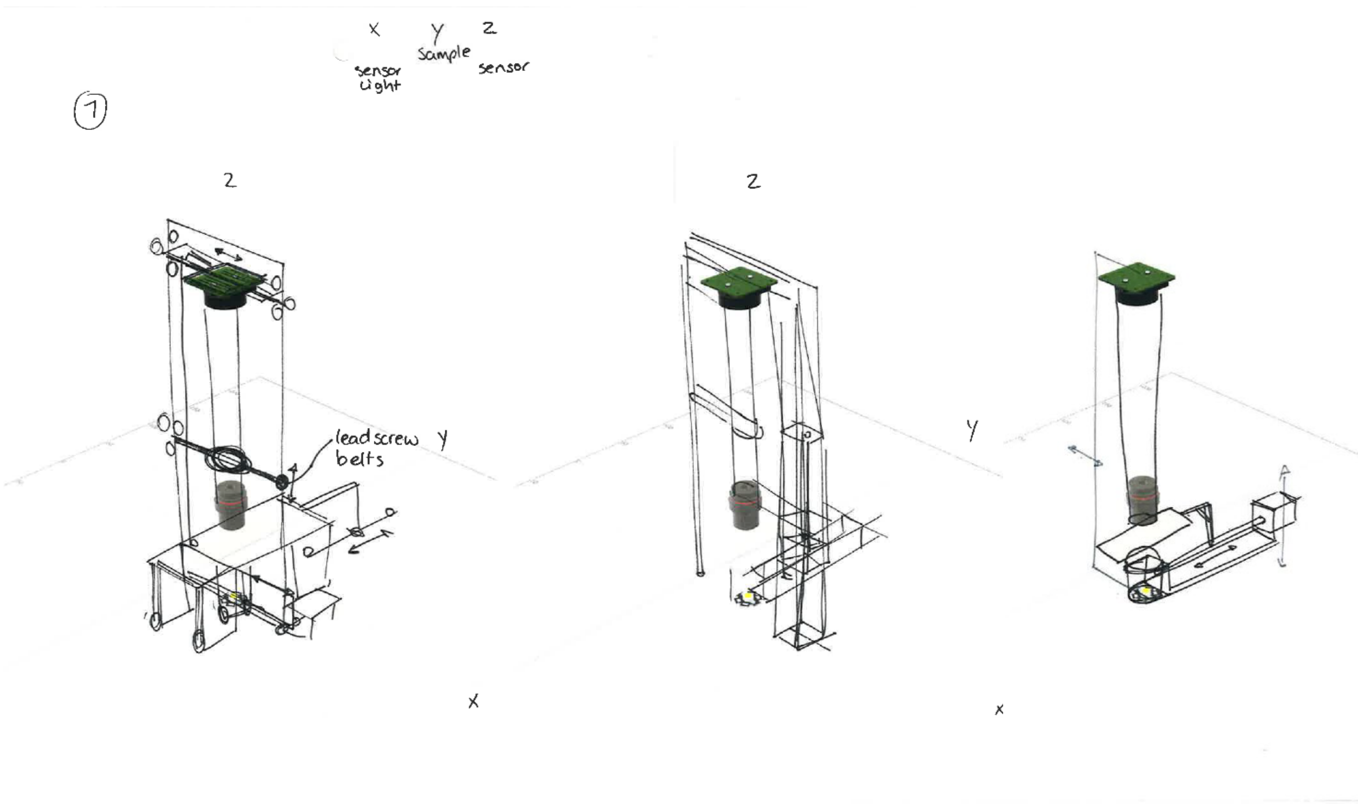
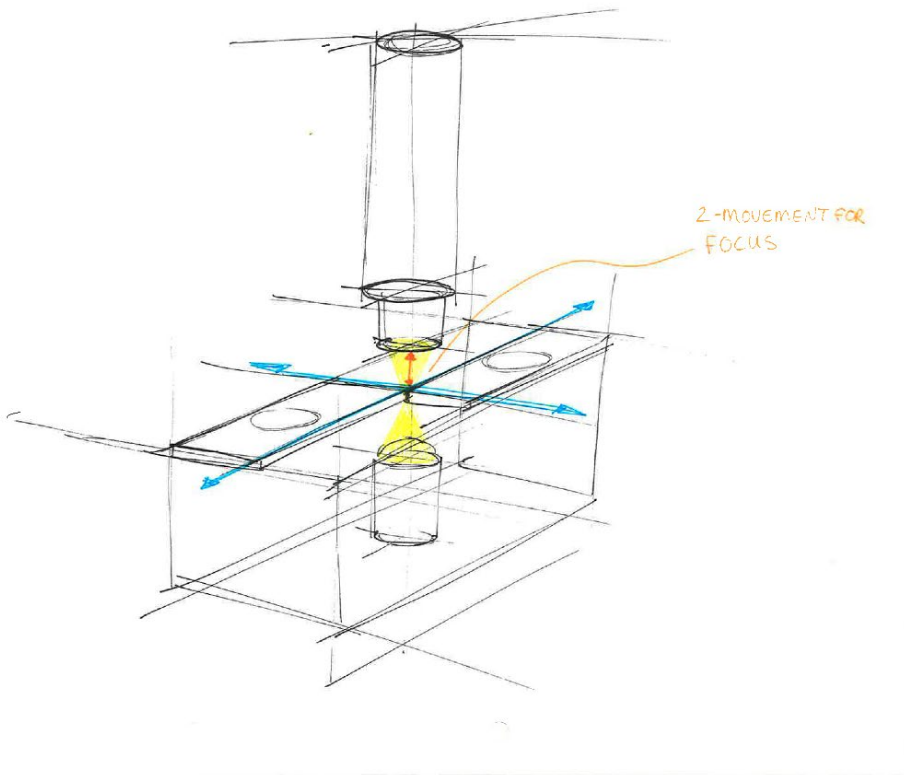

x
y
z
sensor
light
sample
sensor
7
z
z
lead screw
belts
y
y
x
x


Z-MOVEMENT FOR
FOCUS

Ingeborg Braakman

August 27th, 2021

Master thesis
Master Integrated Product Design
Faculty of Industrial Design Engineering

Graduation Committee
Chair: Dr. ir. J.C. Diehl
Mentor: ir. J. Trappenburg
Mentor: Prof. dr. ir. J.M.L. van Engelen

Delft University of Technology
Faculty of Industrial Design Engineering
Landbergstraat 15, 2628 CE Delft, The Netherlnds

TU Delft

Figure 1. Frontpage image: Two Schistoscpe 5 devices

Ingeborg Braakman | Master thesis | 2021

TU Delft