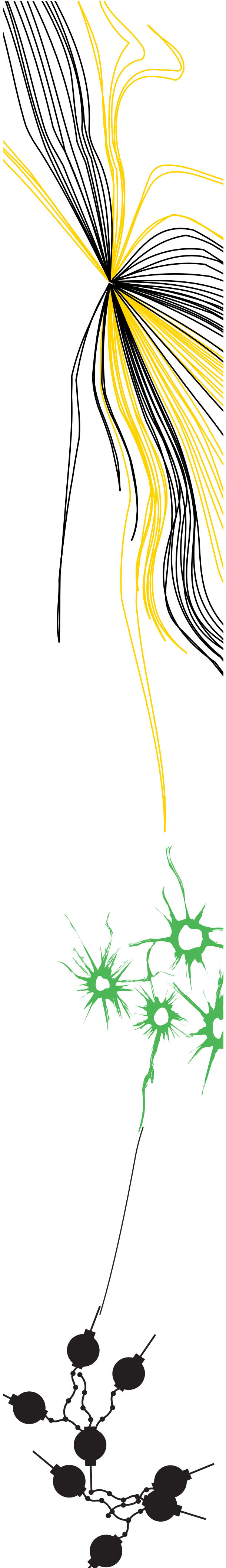

RAM ROBOTICS AND MECHATRONICS

IMPROVING A PROTOTYPE OF AN OPEN-SOURCE RTI MICROSCOPE BASED ON A RASPBERRY PI, TO TURN IT INTO A STREAMLINED AND BETTER WORKABLE MICROSCOPE

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July, 2025

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Abstract: *"This graduation project looks to improve the shortcomings of open-source RTI-microscopes based on Raspberry Pi by means of design. Such as messy cable management, providing a case to house the electronics and improving the workability of the RTI-dome supporting the microscope. More specifically, the improvements in this project were dedicated to enhancing the design of the case hiding the Raspberry Pi and cables thus giving the microscope a finished look. Additionally, improving the RTI-dome by making it consist of multiple parts also hiding the cables, changing the material so it is less reflective and make it able to split so workability with the RTI-dome is increased. The basis of this project is a prototype of an RTI-microscope built by a previous graduation group, based on a Raspberry Pi and an attachable HQ-camera module. To inspect samples they adapted an open-source X, Y-stage, known as OpenFlexure. However this X, Y-stage was later ditched in this project for various reasons. These enhancements are realized using 3D-Printing technology alongside CAD-modeling in Fusion 360. By fastly iterating through different case designs and dome models within Fusion, then printing them to see and test their feasibility, rapid prototypes could be created. In the end a successful RTI-dome that could be split, reducing the time to switch out samples was created. On top of that a functional case design was found that had a modern look to it and was able to hide all of the electronics."*

Contents

1 Introduction

Microscopes are a modern-day tool essential for looking at objects from a close distance. When thinking about a microscope one thinks of studying the cells of a leaf or some micro-organism on a Petri dish. The first microscope was invented back in the 17th century by Antonie van Leeuwenhoek [1], although this sparks some debate. From there on this technology grew into what it is today. A high-tech tool used to observe objects at even the smallest scale. Nowadays, many different types of microscopes exist, higlighting the importance of microscopy, ranging from ones used for looking at the smallest objects such as atoms, to a simple magnifying glass used for looking at an insect [2].

In this project, a prototype RTI microscope is studied and improved upon that was built from scratch based on an open-source microscope project, that goes by OpenFlexure, using a Raspberry PI and 3D-printing technology. This was done by two graduation project students from the University of Twente at their so-called RAM-(Robotics And Mechatronics)-lab, in the previous semester of 23/24-II [3, 4]. This RTI microscope setup uses a camera lens attached to a Raspberry PI to collect images and display them to a computer interface, so it works as a microscope. Around this setup a frame, including an adjustable camera arm, a plateau (X,Y-stage) to put on objects, and a dome are built. The frame itself was completely 3D-printed to make it look and function as an RTI microscope.

Following up on said graduation project and the microscope created in that project. This project aims to improve the microscope by fine-tuning it and adding features that will enhance its usability and user-friendliness. Such as a newly designed fully functional 3D-printed case with a well-ventilated room for a Raspberry PI to fit in. Together in collaboration with: *Ruben Koudijs*, who is going to focus more on the mechanical/electrical engineering aspect of the microscope. And me: *Reinier Davidse*, with a focus more on the design/industrial engineering aspect of the microscope. Thus, both are hopeful for turning the prototype into a fully workable and finished RTI microscope.

1.1 Challenges

This project comes with multiple challenges that need to be addressed and overcome first to end up with a successful and finished product. Starting with: How this prototype can be turned into a refined setup within the given timeframe of a graduation project and what sub-challenges have to be completed for that. To achieve this an investigation will be carried out into how to improve the electronic casing and the design of the instrument. By doing a user-evaluation and relevant research into design.

1.2 Research Questions:

The main Research Question (main-RQ) given by our client that this project is centered around is formulated as follows:

- What possibilities exist to functionally enhance the current microscope prototype that make it more user-friendly?

In answering the Main-RQ a subdivision is made into sub-questions (Sub-RQs) so the main-RQ can be answered in parts, these are formulated as follows:

- What re-designs have to be made to turn the microscope from prototype into a finished microscope?
- What does a finished microscope look like / what do microscopes out in the market currently look like?
- How will the re-design of the microscope improve the usability and satisfaction of the end-user?

1.3 Outline

The thesis is structured into different chapters that explain step by step what needs to be done: First and foremost a literature review is conducted to understand the given situation better and learn more about the given subject in this case RTI-microscopy and Raspberry Pi. Also, this research aims to answer the main and sub-questions asked. After that a method is given on how the prototype can successfully be finished meeting all the requirements of the end-users. From there on design concepts will be generated that can improve the microscope and fulfill the given requirements. After which the design concepts will be tested and implemented into the prototype. Once implemented, the newly re-designed prototype will be evaluated with the end-users. Possibly, leading to new requirements or insights that can lead to additional design features that need to be added. Lastly, it is time to come to a conclusion and see if the re-design of the prototype was a success or not.

2 Literature Review

Before any work can be done on implementing the clients request to improve the microscope in any way. A comprehensive investigation is done to better understand the scope of the project. This investigation is based on multiple research papers that are mostly related to RTI-Microscopy and fields in which they have been used. Starting off with a breakdown of the basics of the usual microscope found in most high school labs.

2.1 A Brief History of Microscopy

As mentioned during the introduction, it was invented by Antonie van Leeuwenhoek, although there is some discussion around this. Its first applications were in the study of textiles, because Antonie van Leeuwenhoek used to be a cloth merchant, and this is why he needed a magnifying glass in the first place, to examine the structures of cloths from a close distance [5].

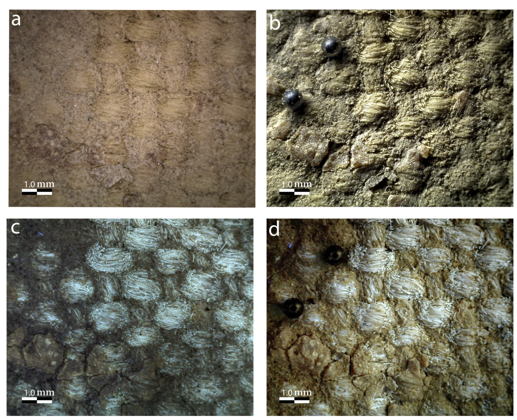


Figure 1: Textiles as observed under a microscope. [6]

Antonie van Leeuwenhoek shaped the first microscope by attaching one lens in between two metal plates and attaching the preparation (later in this thesis described as X, Y-*stage*) to the lower bottom of the pole. At the time his lens setup was able to zoom in much further than other similar lenses used by rivalries [5]. Later on, through this setup and by investigating other structures than cloth, he discovered small organisms that were moving around. This also set the basis for microbiology.

Figure 2: First Microscope made by Antonie van Leeuwenhoek

2.2 What is a (RTI) Microscope?

The basic definition of a microscope is a highly magnifiable lens that is capable of focusing on a (very) small object, objects too small to be seen with the naked eye. Microscopes consist of multiple parts as seen in Fig. 3. The total magnification of the microscope is defined by the following parts:

- **Objective Lens x Ocular Lens (eyepiece) = Total Magnification**

An object of interest to be observed is placed on the stage (see Fig. 3), which is located directly under the lens. The magnification of modern-day microscopes can reach x1000, which means that the object on the stage appears 1000 times bigger than it actually is [7]. Through these levels of magnification, the observer is able to explore the world known as the *"microkosmos"* [7], from insects to very small cells.

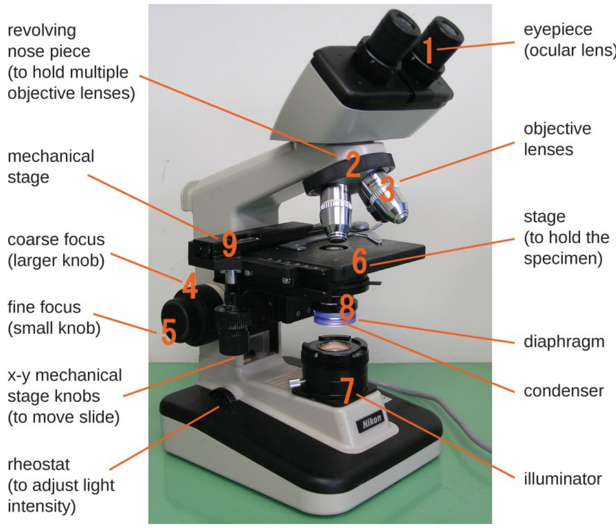


Figure 3: A Microscope and all its individual parts

What makes a microscope an RTI-microscope is by outfitting it with an additional electric dome. RTI is short for *Reflectance Transformation Imaging* and it is used within a wide array of fields. This electric dome, or as it is often referred to as a so-called RTI-dome is placed on top of the (mechanical) stage, in between the lenses used to view a certain object (see Fig. 3). In short, the RTI-dome has LED-light strips inside that can be turned on/off electrically through software. The goal of the electric RTI-dome is to light up that specific object, on the stage, from different angles.

2.3 How does it work (an in depth analysis)?

RTI functions, as discussed briefly, through an electric dome that is able to fully enclose a certain object of interest. On top of the dome, through a hole left open in the dome, a microscopic lens can capture images (from a stationary position). Inside this dome there are multiple layers (see Fig. 4:a) of light divided over strips (see Fig. 4:c). That, if activated, illuminate an object from different angles. An example of this can be found in the first image (Fig. 4), where the colored lines, in a, represent the angles around the dome on which the lights are layered in a sequence over multiple strips, like the skeleton seen in 4:c. And with Fig. 4:b, being the outside of the dome that closes off the object placed on top of the stage [8].

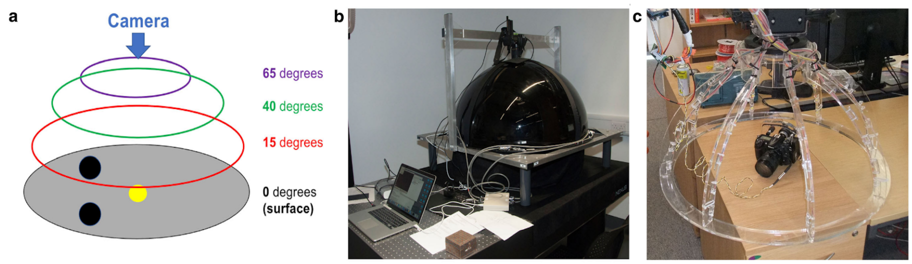


Figure 4: Explanation of RTI-dome (slightly edited by the author to fit horizontally) [8].

As already explained, RTI requires a dome placed on top of a plateau that is moving the object. In addition, the object must be fully enclosed between the dome and the plateau. This is so because, RTI works best if no external light is allowed through, so only the LEDs placed inside the dome produce light. On top of that, RTI works best if the color of the dome and plateau are dark, preferably something like a matte black or black fabric (see Fig. 4:b). And something that is not shiny (unlike Fig. 4:b), so that none of the light transmitted by the dome is reflected inside of the dome itself [8], because that could interfere with the calibration at a later stage.

2.4 Similar techniques.

In the fields of microscopy as well as photography, a wide range of competing technologies exist that are similar to RTI, or within the fields of photography try to achieve a similar thing, to as what RTI tries to achieve and can be used on top of RTI. To explain a few of these:

- Photogrammetry,
- Stereoscopy,
- H-RTI,
- Focus stacking.

Firstly, photogrammetry is a technique where an object from a central viewing point is photographed from multiple angles to create a 3D-Image. A computer program is used to find the intersecting points from these images taken at multiple angles, and creates a 3D-image [9]. The difference between RTI and Photogrammetry is that in RTI only the lighting changes from different angles. As opposed to photogrammetry, where the camera/lens changes angles. In both techniques the object stays at a central viewing point.

A very similar technique to *photogrammetry*, is a technique known as *polynomial texture mapping*, a technique originally developed by Tom Malzbender in HP labs [9, 10]. He designed it to improve 3D-Graphics by sampling and then rendering real-world objects [11]. Those images (made under different lighting conditions) are usually put inside of a computer program that, from the light bouncing off the surface of an object, can calculate a normal vector. Going around the object with different lighting setups, the computer collects and calculates multiple normal vectors, from which it can calculate the topography of the object. That can be turned into a virtual 3D-topography to simulate the object in a program in which it can be further inspected [8].

This technique can also be applied to RTI, by taking the 360 images collected from the microscope and turning them into a 3D-topography that can be turned into a CAD-model. These 360 images are taken when the dome is lit up from different angles, the microscope lens then captures an image at each position. These pictures taken from multiple angles can then be edited into one image, through a computer program like Photoshop, such an image is called a composite image. Doing so will result in a composite image that can be thrown into a program like RTI-Builder to further inspect it. Similarly such an image can be thrown into a program like Blender to turn it into 3D-Object.

Secondly, stereo photography is a technique used in photography where a camera has two lenses to simulate human binocular vision, adding more depth to an image. Also known as a stereoscope [12]. Basically, this technique uses two camera lenses that are positioned very close to each other like a pair of eyes (see Fig. 5).

Figure 5: Picture of stereoscope in Langezijds at University of Twente, with two lenses visible.

Thirdly, another very similar technique is H-RTI, short for Highlight-RTI. H-RTI avoids the need for a completely closed off dome but still uses the very same principles as RTI (see Fig. 6). Therefore, making it more flexible and easier to use out in the field. This technique has even been successfully implemented in underwater scenarios.

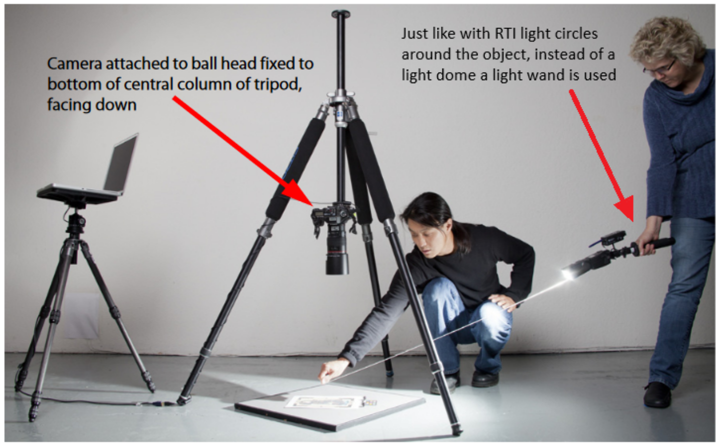


Figure 6: Drawn picture of H-RTI (adapted by the author to explain it further). [8]

Lastly, focus stacking is a technique used in the field of photography in which multiple images are taken of the same object but with the object in a different focus. These images are then leveled on top of each other, in other words, *stacked*, in a program like Adobe Photoshop to create a perfectly sharp object in the picture. This technique can also be applied to RTI microscopy [13]. The lens captures an image of the object in different focus and later these are put together in Photoshop to create a perfect image.

2.4.1 Post-Processing Techniques

Additionally, through software *post image processing techniques* or *different types of lenses* can be applied to enhance the outcome of the captured images and highlight certain details better than without those techniques. One of which is to use an *Infrared Camera* instead of a camera that captures the light visible to the eye. A technique known as IR-RTI. An added benefit of IR-RTI is that it does not capture color. So, for example, in the case of graffiti murals found in ancient caves, in this case the Catacombs of San Giovanni, Philadelphia [14]. A comparison was made between VIS-RTI (described in this paper as RTI) and IR-RTI. The results can be seen in Fig. 7: In the far right, the results show both the color and the depth of the image, and in the result of IR-RTI some crack that was painted over becomes more visible than before in VIS-RTI.

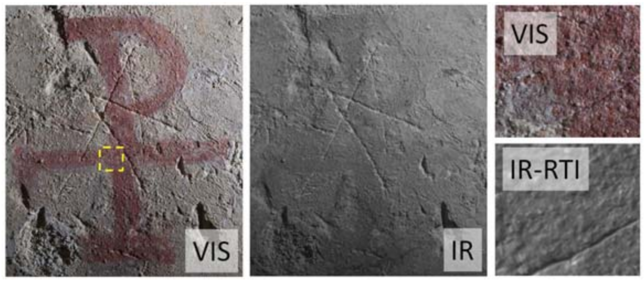


Figure 7: RTI (VIS) compared to IR-RTI (IR).

Post-processing techniques include RTI-Builder, a program specifically designed for RTI-microscopes that is able to process multiple captured images of an object with the microscope under different lighting conditions of the RTI-dome. In addition, this program can add computational filters to enhance certain details even more. The outcome of some of these filters can be seen in Fig. 8. By selecting different post-processing parameters, much more detail can be given to point out certain details. For example, with the applied filter in Fig. 8:b, surface variations are pointed out more easily and thus provide new insights into the meaning or reveal a previously hidden detail, like that there is a shape of a fish, a crown and the letters: *"RVDO"* put on the pipe [8, 15].

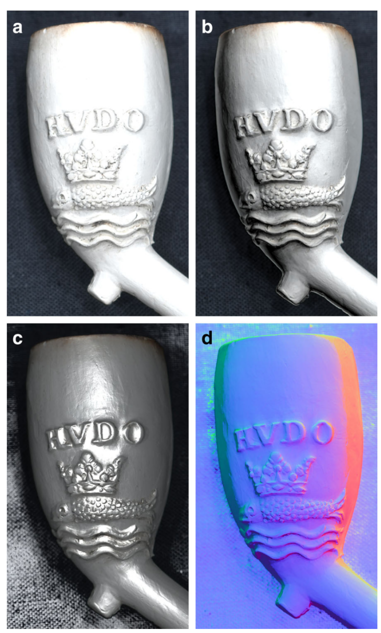


Figure 8: An Old Pipe shown with different RTI parameters. [8]

Furthermore, something like a black sphere needs to be placed inside of the dome for the post-processing software to make sense of the direction of lighting the dome is emitting from. It needs to do this to help with the calibration process in RTI-builder [8]. Once, the black sphere is placed inside of the dome the calibration process can begin, all the lights are turned on then off after each other to create a set of images that can be put inside RTI-builder, the program then calculates the normal vectors and from there on any object that has gone through this sequence can be inspected inside the program under multiple different parameters (see Fig. 8).

2.5 Uses and applications of RTI microscopes.

Initially, RTI was developed primarily for studying the relief of objects or artifacts. Unlike traditional microscopy, which is used much more for research that looks at plants or cells. RTI achieves this because light emitted from the LED strips inside the RTI-dome can bounce off into even the tiniest cracks of an object (see Fig. 9). Using this unique feature of light, more details are therefore highlighted [16]. The light bounces around into the microscope lens that sends these images to the Raspberry PI for further processing.

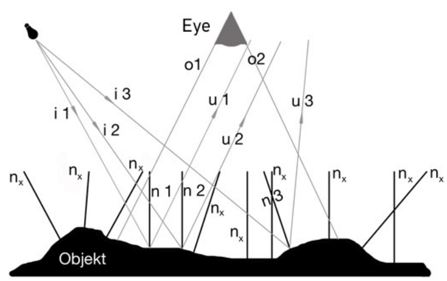
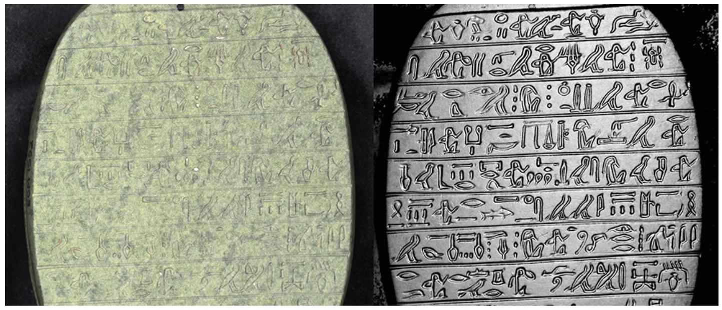


Figure 9: Physics of light bouncing off of a surface: With i.1-3 being the incoming light-rays from the light source, and u.1-3 being the out coming light-rays [16].

RTI is being used in many different fields. Like observing artifacts in a museum, for example, a coin dug up from underneath the ground. Using RTI, new information can be discovered about the surface details of these artifacts (in the *coin* example), possibly revealing hidden details that had not been seen before with the naked eye or a traditional microscope [17]. An important usage of RTI is within the field of Egyptology, a branch within archaeology that studies, among other things, Egyptian hieroglyphs. And thus, can highlight surface details better of such hieroglyphs (see Fig. 10) and point out the unique shapes and meaning between these hieroglyphs.



Egyptian scarab with inscriptions, Eton College Myers Collection, Eton College. Left: RTI "default" mode: mathematical relighting has not been implemented. Right: RTI "specular enhancement" mode: mathematical relighting has been adjusted to show details difficult to discern with the naked eye. Image courtesy Carla Schroer

Figure 10: Egyptian Hieroglyphs under normal ligthing and under a RTI configuration (*without any image processing*)[18].

Within many more branches of archaeology RTI plays an important role like the study of textiles found at archaeological sites. By identifying their raw materials, spinning techniques and patterns a conclusion is possibly reached about their date of manufacture or what type of material it was woven from [6]. Another example is in the study ancient coins found at these site. RTI is easily able to distinguish cracks from the surface of these coins [17]. As well as, making out details on these coins that with the naked eye are hard to see because of wear.

All in all, RTI is a useful tool within various branches of archaeology able to give more insights into artifacts found at digging sites than with conventional microscope tools. Furthermore, highlighting details or revealing secrets that would otherwise not have been discovered. Thus a real game changer within the field of archaeology.

2.5.1 Benefits of RTI

- Relatively cheap microscopic technique that gives qualitative information about an objects surface structure.
- DIY projects available.
- Modular, can be outfitted to an end-users requirements specifically. Can be scaled (dome).

2.5.2 Downsides of RTI

- Requires a dome that needs some understanding of how to use it effectively.
- Requires a HQ camera.
- Needs to be calibrated and requires understanding of how to do that.
- Understanding of Raspberry PI.

2.6 Comparison of other RTI systems.

Within different fields of research custom DIY RTI-microscopes were used.

2.6.1 Highlighting Natures Beauty

A very interesting application that made use of RTI is within the project [19]: "Illuminating nature's beauty: modular, scalable and low-cost LED dome illumination system using 3D-printing technology". In this project a low-cost RTI microscope was built by a group of researchers for their own research purposes, and they were able to get some very impressive results. The results included beautifully crafted pictures of insects, etc. obtained from an archaeological museum. All parts were printed by themselves using a 3D-printer, and the shape of an RTI dome was designed using blender.

The dome from Bäumler et al. came with some handy features that made their RTI setup even more advanced. One of these features was that while the dome was applied to the plateau, the plateau itself was still able to move freely so that the object underneath the dome could still be looked at from different angles. Another interesting feature on their dome was an adjustable opening, or a so-called Iris diaphragm (in photography often referred to as a shutter), which made it possible for them to adjust the opening of the dome; see Fig. 11. Another specification mentioned in their assembly was the use of Angel Eyes LED rings, neutral white 6000 K, to highlight their objects of nature in the most natural way.

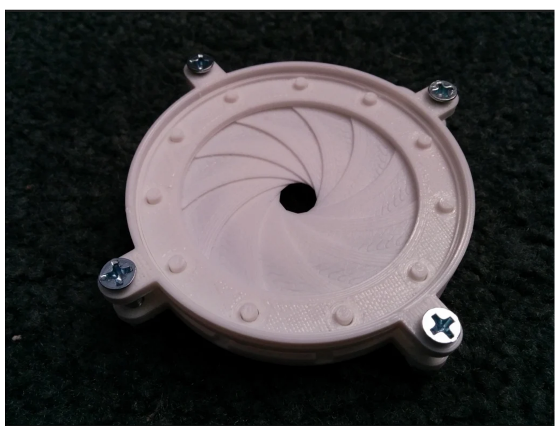


Figure 11: Adjustable Opening as used in their paper, found on ThingiVerse. [19]

2.6.2 Previous Microscope

During the Introduction paragraph it was already explained that this project builds further upon an already existing prototype of an open source microscope platform built by a previous graduation duo at the University of Twente, Matei Obrocea and Olivier Donker. The platform they used is called Open-Flexure and is a 3D-printable microscope built alongside a Raspberry PI microcomputer attached to a Raspberry PI HQ camera module (provided by the same client [3]). Open Flexure was used as it provides a good base for the previous project where they tried to only build a prototype to proof that their concept was working. Open-Flexure comes with a 3D-printable body and has a functional x,y-stage, also known as the microscope plateau, that holds and moves the object [20]. What they added themselves was an arm that holds the HQ camera module and can move upside down along a worm gear, in the z-direction compared to the x,y-stage [3]. As well as a computer program that can capture images from the HQ camera and move the plateau digitally as well as physically [4].

All in all, the Open Flexure project was successfully implemented into a fully functional microscope. However, with that being said some things were overlooked in user-friendliness.

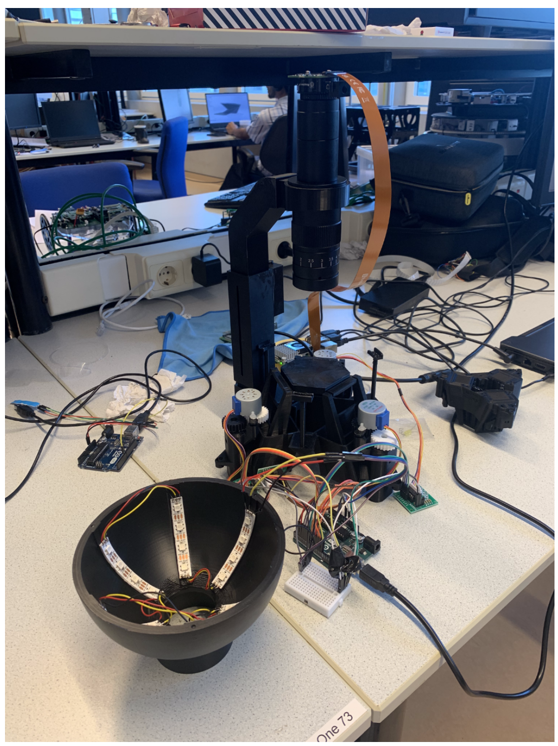


Figure 12: Picture of the Old Microscope based on OpenFlexure [3]

2.6.3 Updated Microscope

While this thesis is done within an extended period (till mid-April as opposed to end-January) the microscope has come with already a quite extensive update compared to the work done by the previous group of students that got it started. Namely because my colleague Ruben Koudijs managed to finish his work in time and thus got his part already finished by the end of January. This means that the X,Y-stage of the microscope got a completely new overhaul and works much different from the previous version. On top of that much of the RTI software has been implemented within the microscope making use of the attached Raspberry PI. So, the microscope can now autofocus, take images and process these within a given software that is able to give a better 3D-overview of the object lying underneath the lens of the microscope, completing the RTI-part. Moreover, this microscope comes with a temporary foot design so it is able to stand up correctly.

These processes were all developed from scratch. It is also important to mention that the microscope is now completely mechanical and can be interacted with through software, therefore, the X,Y-stage along with the Y-arm, that holds the lens of the microscope and can move it up and down, are connected to motors that are controlled with a software interface. So, no need for a knob or buttons on the body of the microscope anymore. See Fig 12 And Fig 13 for a comparison.

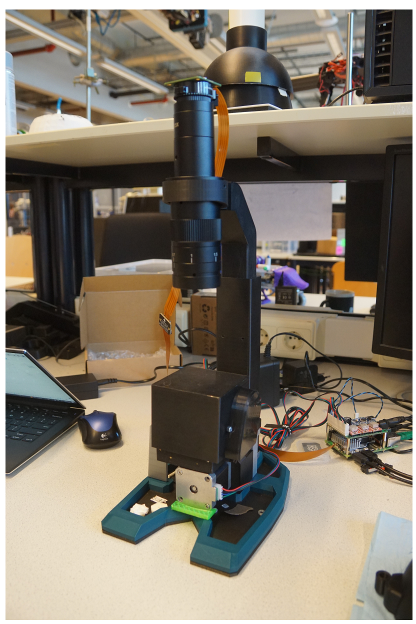


Figure 13: Updated Picture of Microscope with the newly designed X,Y-Stage in place + Foot at the bottom.

2.7 Conclusion

In conclusion, enough open-source RTI microscopes exist that have been tested out in the fields. Many of which have also been built by a group of researchers themselves using 3D-printing technology. The added benefit of it is that it is highly customizable and scalable for different purposes. Purposes include archeology in which it can highlight information hard to see under normal microscopes. Other purposes were found as well like 3D-height-mapping such as PTM. And it has also been used for artistical purposes like highlighting the beauty of nature.

3 Design Methods

To arrive at a feasible and finished product that satisfies the wishes of the end-user, a design methodology is used within the sector of Creative Technology, described by Angelika Mader [21], and goes through four different phases iteratively (see Fig. 14) aimed at coming up with the best solution possible. It is described as follows:

3.1 Ideation Phase

It all starts with a product idea, a design question given by a client or a personal creative inspiration. From there on more ideas on the possibilities of the product start to be generated. These can either come from more creative inspirations or are based on reasoning like a need for something in society. Another approach is by looking for related work, this can give insight into what is already out there and how other designers solved the same problem.

3.2 Specification Phase

In this phase multiple solutions to the design questions found in the Ideation phase are explored with several lo-fi prototypes. These prototypes are laid out with the end user and possible users of the end-product itself. Within this phase the end-user requirements can change as well as the requirements for the product itself. Because these prototypes are meant to give new insights into the functionality of the product.

3.3 Realisation Phase

Once the product has been specified and an early prototype has been successfully evaluated, work can be started on the final prototype / finished product. This step requires acquiring the right components, materials and electronics etc. Then the product can be put together: fitting the electronics, shaping the product and so on.

3.4 Evaluation Phase

Lastly, the evaluation phase confirms that the actual product meets the end-user original requirements that were determined early on. By re-evaluating the product with the client and possible end-users. Of course, this is already done in the specification phase however in this phase no new user-requirements should come up, at least none that are detrimental to the experience the product should offer.

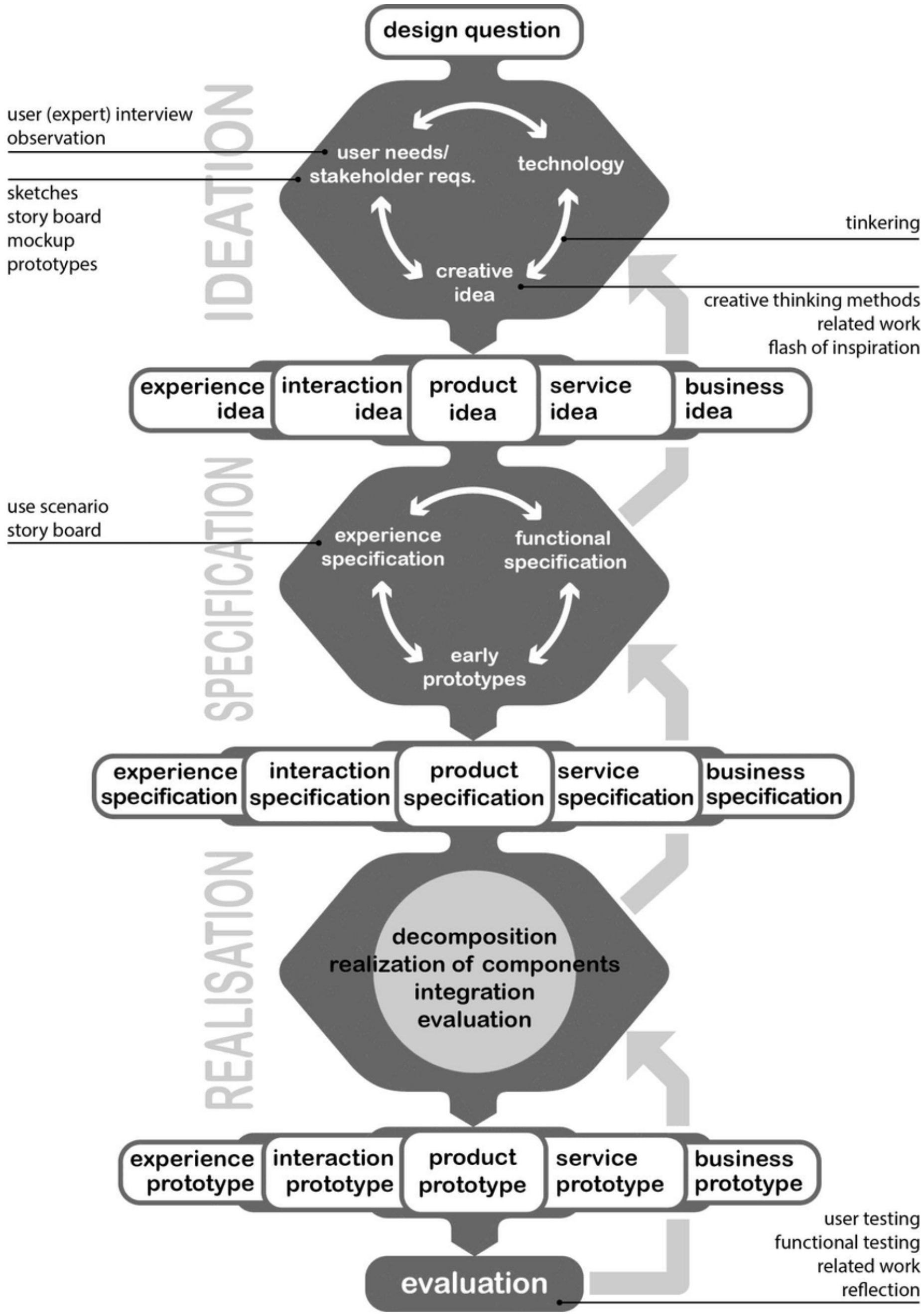


Figure 14: A Creative Technology Design Process [21]

3.5 Overview

Knowing the above steps they can now be applied to the scope of this project. The project started off with a broad design question given by our *client* and *supervisor*. The question posed was somewhat along the lines of, and similar to the one in the introduction: *"Further improvement of a microscope prototype built by a previous graduation duo"*, to be clear this was the original question that evolved into the RQs posed in this research paper.

This evolvement started with taking a closer look at the microscope prototype and having a conversation with the previous builders of the prototype. It became clear early on that there was much room for improvement. Knowing what to improve the end-user was questioned to confirm these improvements.

The next step is to apply these improvements to the actual prototype by means of design. Following up on that is testing to see if these improvements have an actual improvement on user- satisfaction. This will be done through a questionnaire and by observation of the interaction between the end user and the final product.

3.6 Techniques

To realize this design process in the best possible way, multiple known and taught techniques are used. Specified a bit more in the following subsections. The techniques used are as follows:

- Interviews and Meetings,
- Prototyping,
- Software and Hardware.

3.6.1 Interviews and Meetings

The full length of the interviews, including date and key-points can be found in the Appendix A. In this section a quick summary is provided, so the main points are clearly laid out to the reader and understood while further reading the text. The interviews were done with our main-client and supervisor: *Pep Canyelles Pericàs* as well as our end-user: *Carol Derla*. They covered a wide range of topics, but were mainly about their wishes and expectations for further improvements to the microscope that was previously built and realized. A list of improvements was derived from these interviews:

- Enhanced design of the microscope body,
- Hiding the cabling that goes from the motors to the Raspberry Pi,
- Ventilators inside of the case,
- An RTI-Dome that splits,

- An increased movement of the X,Y-Stage,
- A functional improvement to the Z-Stage,
- A more user-friendly user interface (UI).

With these improvements in mind the project can be steered into the right direction so that the features added to the microscope are clearly in line with the wishes of the client and end-user. Of course these features will be tested and confirmed in further interviews and meetings.

3.6.2 Prototyping / Trial and Error

To go from a concept on paper to an actual product, multiple designs had to be created and realized, this process is also known as prototyping and relies in some degree on trial and error. The whole process and how it turned out is described in more detail in Chapter. 5. Here a quick definition is given. Moreover, prototyping is an easy tool to quickly work an idea out in reality and evaluate it with an end-user or client. Thanks to modern day tools like 3D-printing a concept can easily be put to the test. Compared to foam modeling, which requires more skill and up to a certain skill level is less precise in achieving the designers vision. Therefore, this project makes great use of 3D-printing.

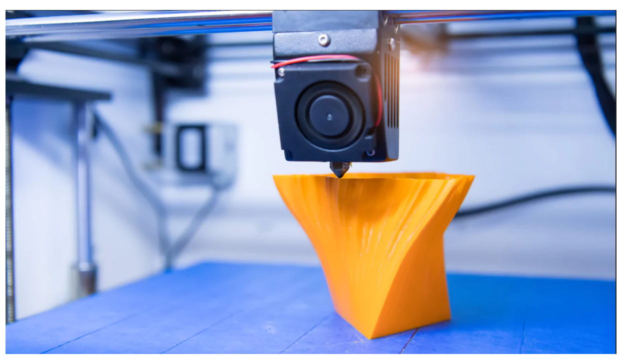


Figure 15: 3D-Printer in process of printing, layer upon layer. [22]

3.6.3 Software and Hardware

In the whole design process different software and hardware is used. With two programs mainly being used. This is Autodesk Fusion 360, which is a software program that lets you design 3D Cad models with realistic measurements in *mm*. And a slicerprogram, one like Ultimaker Cura 4.1.1.0, which is needed to turn these CAD-Model into actual 3D-Printable objects. Fusion 360 is used instead of a program like Blender because of its more engineering focused approach and one important feature as mentioned the realistic measurements.

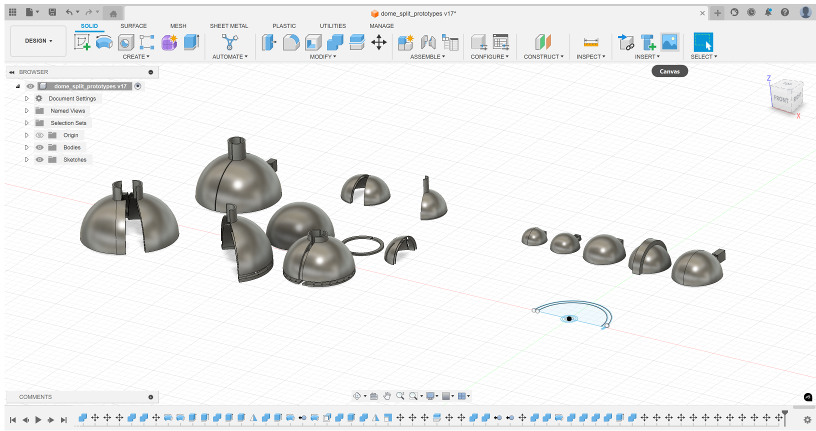


Figure 16: A screenshot of the workspace in Autodesk Fusion 360 taken by the Author.

These realistic measurements are important. As said, the next step involved requires precisely 3D-printed parts. This is also the hardware that is mainly being used, 3D printers. 3D printing is a technology that is good in rapid prototyping and the design of difficult shapes. The 3D printers mainly used are the Ultimaker S5, a 3D-printer by the company Bambu Lab and an Original Prusa MK3S+.

Figure 17: Ultimaker S5 [23]

4 Concept Generation

4.1 Initial Ideas

Here are a few concepts laid out already. The first concept (see Fig. 18) is changing the dome from a round surface into a hexagonal surface. This has the benefit of a more flexible layout for the RTI lights as seen in the picture mentioned. Furthermore, it adds some aesthetic value because it increases the look of the dome into something unique and exotic. On top of that this dome has its own power supply and can simply be charged with a USB-C cable, something to possibly look into as well.

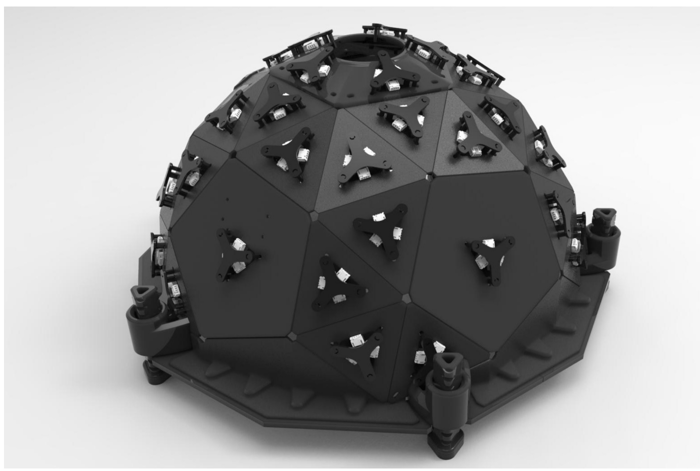


Figure 18: Hexagonal Portable Dome by Dodec Labs LLC [24]

Secondly, adding a knob to the arm that holds the microscope lens (see Fig. 19). This will increase the workability of the microscope because a knob now simply can be turned to change the focus. Instead of having to kind of stroke the worm gear with one of your fingers as is the case right now that is less intuitive and sometimes does not work well and overtime will wear out because it is plastic rubbing against a plastic gear. But for a prototype it works very well and is easy to manufacture and test.

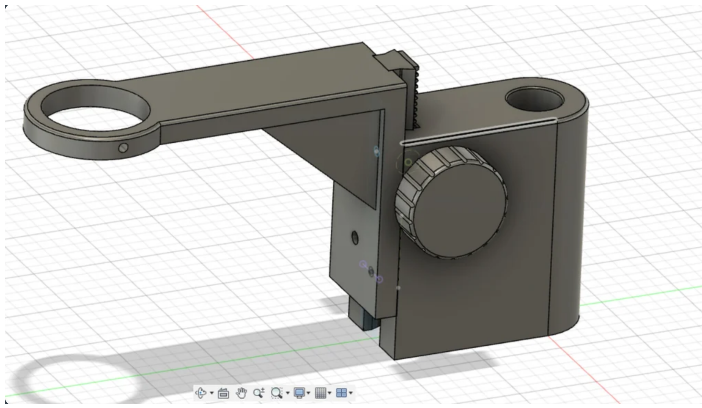


Figure 19: Adjustable Microscope Mount with Knob found on Thingiverse [25]

Thirdly, adding a hinge to the dome (see Fig. 20) so it can be attached to the arm of the microscope that is holding the camera. Including a mechanism that enables the dome to safely be split in half. Meaning, all the LEDs and cabling can still be inside of the dome while it splits open and remain safely in place at the same time. The reason for this is that it makes samples easier to switch out on the plateau. And thus, it increases the efficiency and workability of the microscope. Of course, adding a split to the dome decreases the light-proofness which is in contradiction to one of the main-goals of the dome to increase the light-proofness, so this is something that needs to be taken care of as well. For example, by adding a crease.

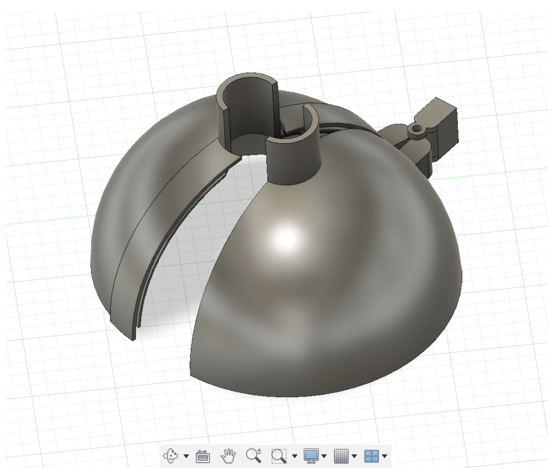


Figure 20: Early Adapted Model of a Dome With Hinge (built by the author in Autodesk Fusion 360)

Fourthly, creating a hinge that opens up like a butterfly door from a super car. This will increase the workability of the microscope even more because the dome now does not come in the way of the plateau anymore instead it remains on the outside. Moreover, this will increase user satisfaction as it becomes more satisfying to look at the dome open. It will also give the microscope a more luxurious feel as Lamborghinis are known for their luxuriousness.

Figure 21: Hinge like Lamborghini Doors [26]

Lastly, another idea that came to mind was to increase the modularity of the arm by switching out the bold that connects the arm to the grip holding the camera module for a backpack clip. So, one does not have to unscrew a screw but can simply, like a backpack clip, unclip the camera holder from the arm and switch it out with a new one.

Figure 22: Backpack Clip Mechanism [27]

An essential part ofcourse is the custom design for the microscope body, as any microscope needs a casing to hold all the parts together. Custom means designing a new body for the microscope that is pleasing to the eye and works well with the newly designed microscope plateau (designed by my colleague Ruben Koudijs) as well as the RTI-dome.

Meaning, leaving enough space for the plateau to move around as well as ensuring that the RTI-dome is able to enclose an object perfectly without letting any light through. It also needs a dedicated space for the electronics so that they are hidden away from view to the user but still remain easily accessible. As can be seen in Figure 23, most microscopes have a very simple casing, with the focus mainly being stability. A secondary goal is simplicity, being able to move the arm up and down quickly and changing the focus as needed without too much hassle or (re)moving the object in view.

Figure 23: Common Design of a Microscope Body [28]

5 Specification

Going from a concept to a finalized idea and product, the next stage within the design process is to develop a working prototype based on a selection of the generated design concepts. That also fulfills all of the end-users' needs, as laid out already in the previous chapter (3.6.1). The concepts that were selected and tried out during the prototyping are as follows:

- Splittable Dome Concept,
- Backpack Clip,
- Expensive Looking Hinge (based on Lamborghini doors),
- An Updated Case Design,
- Lens Diaphragma (Based on a paper from CH. 2 [19]).

With these concepts in mind the prototyping could begin to figure out what works well and what does not.

5.1 The Dome

Finalizing the dome design required multiple iterations of prototypes to be created. The dome in itself was designed in Fusion 360 and each time printed on a 3D printer. Each of these prints tested out a new concept or idea to see what works well in reality. Starting off with making a dome that could be split open. Following up on that designing a dome that consisted of multiple parts: An inside layer and an outside layer. To create a gap in between where electronics and cabling could be stored and hidden away. Finally, finding a way to attach all of these parts together, the dome halves and these to the arm of the microscope.

5.1.1 Prototype V1

The very first step in making the dome was to design a hollow dome within Fusion 360, quite an easy task for anyone who has just a small bit of experience with this program. With this basic dome design, a split could now be made exactly in the middle to create the two dome halves. On the outside of these two dome halves a simple hinge consisting of three parts was attached. Two hinges on the halves and one hinge connecting the other two hinges so they were connected together and could later potentially be attached to an arm.

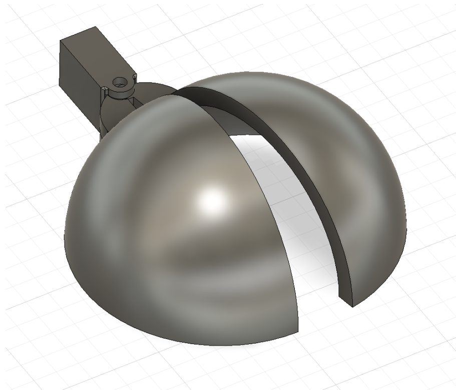


Figure 24: Picture Prot. V1 without hole on top (by author).

With this first idea of a splittable dome worked out, more details could be added. First and foremost, adding a layer in between the halves of the dome to store away the electronics and add the LEDs. Therefore, the dome halves had to be split into a bigger and a smaller sized one. The bigger one to ensure that the complete dome remained light-proof. And a smaller one to hide the electronic cabling but with splits inside so the LEDs could shine through. As well as a ring on either one side of the bigger or smaller sized dome, to eventually hold both parts together. So, simply using the first method to create the dome another dome was made to cut this dome into two domes with exactly the same width. Having done that a method was found to cut exactly six splits of preferable width, evenly distributed on a circle, into the smaller dome.

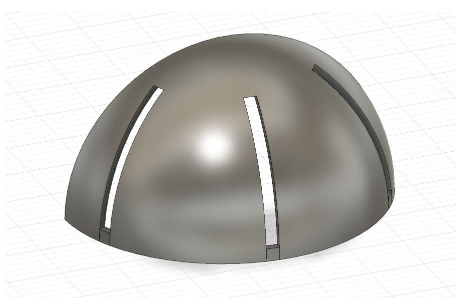


Figure 25: Halve of the inner dome with three splits inside for future display of the LEDs (by author).

Then in the middle of both halves a hole needed to be on top which later should serve as the hole through which the microscope camera will capture. Additionally, with a tube (not yet the right size) on the outer layer of the dome that slides onto the microscope camera to ensure proper alignment and light-proofness. To ensure light-proofness even more one side of the dome came with an overlapping layer on the outside that could slide onto the other side of the dome so no gap was left between the two halves once closed. And with these basic requirements being implemented a 3D-print could be made to test the workings of this prototype. The final CAD-design can be seen in Fig. 20 of the previous chapter, the final print is shown in Fig. 26, 27 and 28.

A simple way was found to hold the two layers together with a simple foot on the outer layer that slides into the inner layer to lock the inner layer inside of the outer layer. It ended up working quite well for this prototype as the inner layer stuck to it by force, without any screws. However, taking it apart again turned out not be so easy and required quite a bit more force than it did to put the halves together.

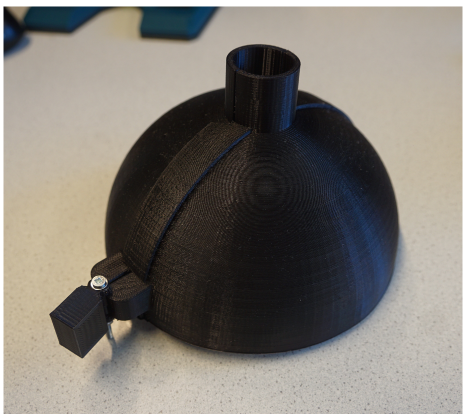


Figure 26: Prototype 1 3D-printed, Top-Down view (closed). With a simple hinge applied to its back.

Figure 27: Prototype 1 3D-printed, Top-Down view (open). With light-proofing applied to the left-side of the dome.

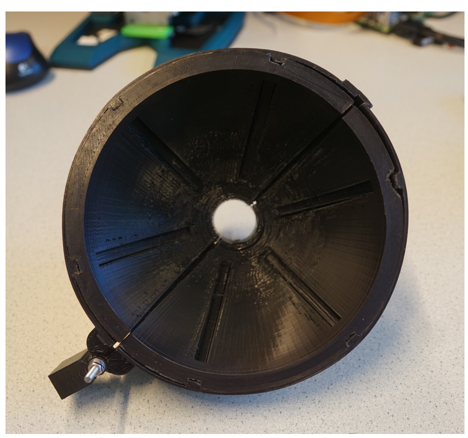


Figure 28: Prototype 1 3D-printed, Inside view.

5.1.2 Prototype V2

Of course, these layers needed to be attached together in some way that they could be taken apart in a future scenario, in case something had to be changed regarding the electronics. So, gluing them together was not an option. Multiple versions were created to try and implement this. One with holes and pins printed inside and onto the dome halves so that they could be slid together. However, this version turned out not to be lightproof as the outer layer of the dome was put onto the inner layer of the dome, leaving just a tiny slid between the two halves in which a tiny bit of light could come through. Furthermore, the pins connecting the two halves were prone to breaking, which in time could render them useless.

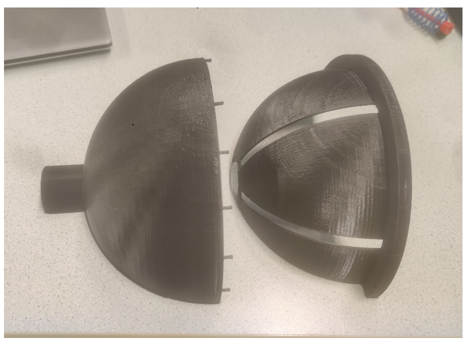


Figure 29: Dome with pins design, photo taken by the author (on a smartphone).

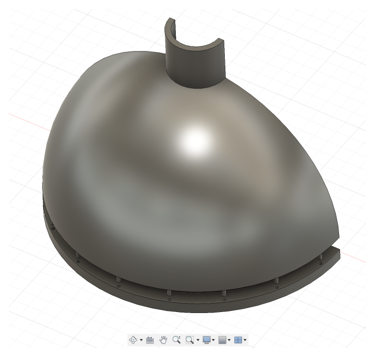


Figure 30: Model of that dome in CAD (made by the author in Fusion 360).

So another version had to be designed with preferably screw holes in both halves of the dome to screw the two together. A challenging design at first because a solution needed to be found on how the screw holes could be put in one half of the dome and then on the other half of the dome as well at exactly the same position with the same size. This required a bit more precise designing within Fusion 360 but eventually it worked out so that both halves had screw holes at the exact same position. A miniature version was printed of this dome (about one sixth) to confirm that the screws would hold both parts together well enough and were in the right place.

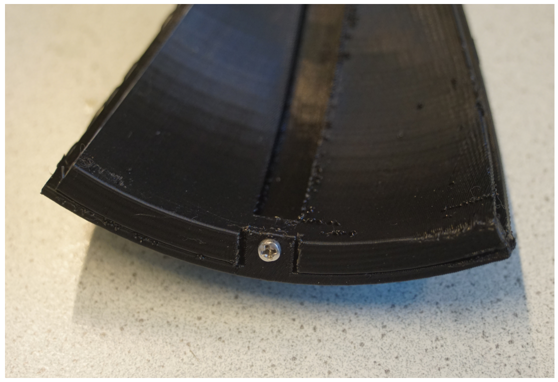


Figure 31: Dome Quarter 3D-Printed to confirm right size of screw holes.

This version worked out the best and was implemented into the final version. Screws with a dimension of 2 mm x 6 mm were chosen as they provide enough tension to hold both layers together and do not take up much space and thus are not visible to the end user or add any unnecessary depth to the dome. Additionally, the dome could be unscrewed and re-screwed multiple times without the screw holes loosening up so if any changes tot the electronics were made in the future this was possible.

On top of that, to make the dome completely light-proof a little extension (tube) had to be put on top that fitted around the microscope itself, this tube needed to be the exact same size as the diameter of the microscope in order to be fully lightproof. So multiple little tubes were printed with different diameters (see Fig. 32) to see which one fitted the best. Eventually, the tube with the best diameter and fitted the best was put on top of the full dome design.

Figure 32: Test print of a tube (approximately 49 mm in diameter)to see if it could fit around the microscopic lens, in this case it did not.

5.1.3 Prototype V3

While designing and implementing it, so that the dome could be split, the realization came to mind that it needed a bigger hinge instead of just a simple hinge to hold both dome splits together. In other words, a hinge that works more like a(n) (robot) arm needed to be designed. This feature would not have been necessary without the light-proofing. But because both splits now needed to be slid exactly parallel to each other so one halve could fit in between the light-proofing of the other halve, a new hinge, as said, consisting of multiple parts was necessary.

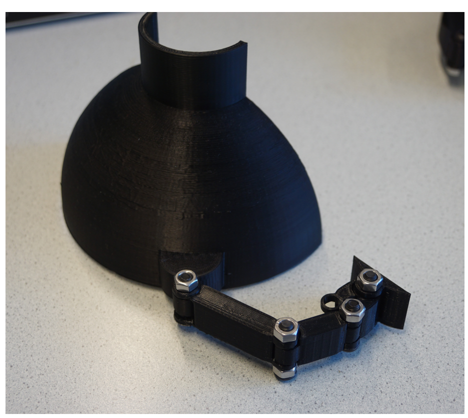


Figure 33: Prototype V3 with newly designed arm attached.

So a hinge as described was designed that consisted of three parts to provide enough freedom of movement for both dome halves to be closed exactly parallel to each other. The hinge on the outer layer of the dome was moved slightly at about an angle of 60 degrees (no precise measurement was taken), to have both halves easily come apart again after closing this confirmed in testing. With that being implemented onto the outer-layer of the dome and the inside (inner-layer) of the dome being able to connect to the outer layer, the dome was almost finished. What remained was to connect the dome to the arm of the microscope so it could enclose the plateau.

5.1.4 Final Prototype

Successfully, having implemented and re-designed multiple iterations, a conclusion could be made about what approach works best for the final design of the RTI-dome. Starting with the design of a model in Autodesk Fusion 360 that matches all of the given measurements, such as the need for a hole on top of the dome through which the microscope can look and capture. This needs to be the right size (about 50 mm). Following that the dome needs to be able to entail the whole size of an object and have room for small objects to be placed underneath, while also not being too big so it fits with the design of the case including the arm.

So a dome was designed with all the given measurements and features that were explored in the previous prototypes. Still a way needed to be found on how to attach the dome to the arm. A simple custom hinge was chosen and designed in Fusion 360, that was able to fit around the arm and came with two hinges that could attach to both sides of the dome, see Fig. 34. Moreover, the dome and its arm, especially the bolts connecting all the pieces of the arm, were found to be quite heavy. Therefore an extra supportive ring (see Fig. 35) was attached to the hinge on which the dome, once closed, could rest so it would not sack, this to ensure the dome was horizontally aligned.

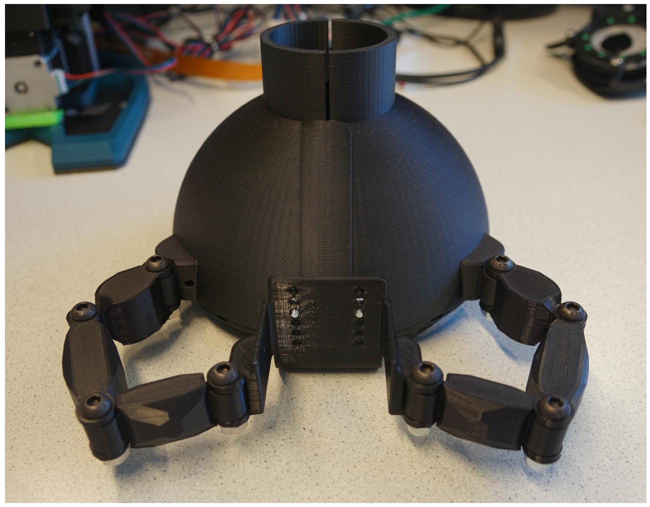


Figure 34: Final Version (closed), with both arms attached to the hinge.

Figure 35: Final Version (open), with the supportive ring in the middle.

5.2 The Case

The design of the case proved to be quite a bit more difficult than the dome. Even though the case was designed after the dome, so in theory more experience in Fusion 360 was there to guide the process. Mainly because of the fact that the case not only needed to look good it also had to be functional and fit around the existing X,Y-stage and arm, moreover, it needed to hide a Raspberry Pi including cables while still providing access to these cables and possibly in a future scenario the Raspberry Pi. So the design of the case went through many steps, with different parts being 3D-printed to test out a range of functionalities.

5.2.1 Challenges and (or) Restrictions

Designing the case proved to be a challenge of its own. As many microscopes look somewhat similar like seen before in Fig. 23. Moreover most microscopes use a hand-driven system to move the platform, however this microscope does not its electronically driven. So not a whole lot of inspiration can be taken from usual microscopes that do not come with a big electronics casing.

Next to that the design needed to be smooth and clean so, not just some case built around the motors that hides everything, that would be too bulky. As well as be able to provide stability to the platform while it moves and when the object of interest is inspected. Especially, when the microscope lens is capturing multiple images of the sample, for example while it is focus stacking or doing a 360 scan with the LED-lights.

Furthermore, since most of the electronics, plateau (X,Y-Stage) and arm were already implemented by my colleague Ruben Koudijs, see Fig. 13. The case had to fit around that plateau and needed to hide those cables. To specify, the mechanism that moves the plateau consists of two relatively big motors that are able to move 20 *mm* positively, from its starting position, in each direction, this then moves the plateau on top of those motors. So the case had to be built around that while still allowing the motors and plateau to move freely.

5.2.2 Requirements

The design of the case needed to be an update compared to the previous case. This meant making it less bulky while at the same time leaving enough room for the already built X,Y-stage to move freely. Giving us the following design requirements:

- 20 *mm* of space at least for the X,Y-stage to move,
- Holes, or open space for ventilation,
- 50 *mm* of space vertically to leave room for ventilators,
- Enough and a dedicated space for the raspberry pi,
- The cables should be hidden to the user,
- The cables should still be easily accessible,
- The design should resemble a microscope,
- (Optional) give it a modern touch, something not seen in most other microscopes.

5.2.3 Implementation

The design started off with a very simple foot that could attach underneath the microscope platform and arm. This was more of a temporary solution so the X,Y-stage and arm could stand on their own, and later on, the dome could be applied to this platform for testing. Moreover, this temporary *foot* had one dedicated hole in it so all the cabling could be put within it and put to the side, slightly cleaning up the microscope. Actually, it had multiple holes in it to reduce the time and material it would take to 3D-print. But, as said, one specifically for the cabling. This foot was successfully attached to the microscope platform and arm, providing enough stability, the whole microscope could even be picked up and transported.

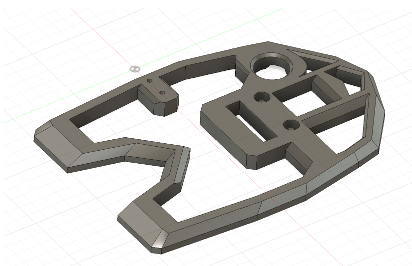


Figure 36: Temporary Microscope Foot.

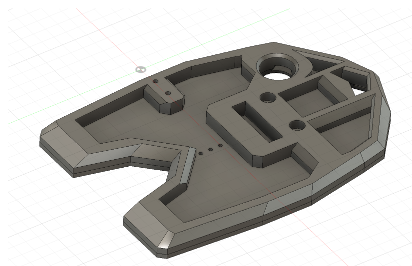


Figure 37: Temporary Microscope Foot + Connector.

Secondly, a thin *connector* plus holes was designed and printed that could connect to the foot and possibly in the future with the holes could connect to the *electronics case*, that still needed to be designed. While this was not planned initially the addition of this connector allowed for temporary storage of small objects that could possibly be inspected by the microscope, the outcome of which can already be seen in Fig. 13. The connector was able to stick to the simple foot without any glue as it fitted perfectly to the foot.

With the connector attached, the idea now was to design an electronics casing that could fit underneath the connector. So work was started within Fusion 360 designing multiple electronics cases. This was done simply by creating two flat surfaces, one bigger than the other that would go underneath and using a 'feature' within Fusion 360 called *'Loft'*, the gap between the two surfaces could easily be filled up creating the simple shape of a case. Actually, the foot was created similar to this, after which holes holes were cut-out. Through this feature different types of microscopic case shapes could easily be created. Just by playing around with shape of the two flat surfaces.

Once a satisfactory shape was created, the insides of the shape could be hollowed-out leaving only the walls. Thus creating a simple electronic case in which, if big enough, the cables, Raspberry Pi, plateau and part of the arm could be stored. If big enough, because it was hard to determine how big the case should actually be and would be based of just creating a 'Loft', as no restrictions could be given using this feature. Many, different shapes were created all those resembling the shape of a microscope, many of which were discarded though as they were either not big enough or had an awkward shape. Luckily, though at some point a good shape was found as can be seen in Fig. 38, which was fitted and tested around the plateau and rest of the microscope within Fusion 360.

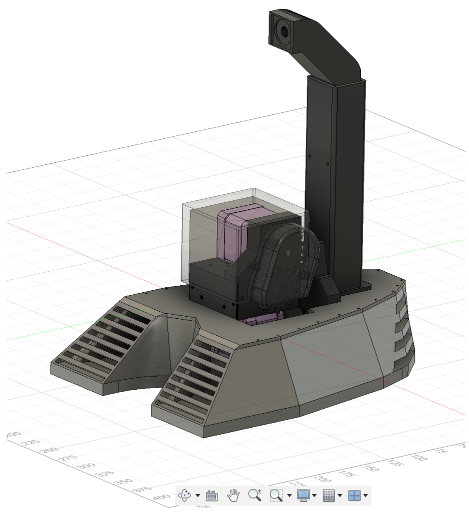


Figure 38: First Fusion 360 Model of the *Electronics Case*

With the general shape of the case ready details could now be added. Most importantly the addition of slits in the front and back serving as the ventilation through which air could flow once the ventilators are installed. Another detail were the holes through which the cables going to the Raspberry Pi are made accessible to the user. Additionally, to actually hide the electronics within the electronics case a plate needed to be designed that would sit on top of the case while leaving room for the plateau and arm to stick out (see Fig. 39). This plate also needed to be removable so if in the future something had to switched out within the case this could easily be done by unscrewing the plate. Lastly, with some adjustments the plate fitted nicely around the X,Y-stage and arm, leaving enough room for plateau to still move around completely.

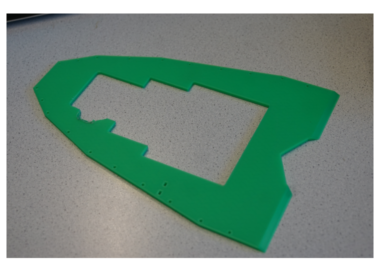


Figure 39: First version of a plate to hide the electronics that can be screwed onto the electronics case, also seen in Fig. 38.

Knowing how to easily design an accessible case in Fusion 360 that could provide enough ventilation to the Raspberry Pi and other electronic parts. A second version of a case was designed that had a focus more on aesthetical value. The process was similar. But now understanding better what the outcome of the 'Loft feature' would be based on the two plates it received, the design could be steered more. Ending up at a design that had a bit more flavor to it, see Fig. 40. Halve of this case was 3D-printed (see Fig. 41) to confirm it was the right size and if it would allow enough space for a ventilator (with a 50 *mm x* 50 *mm* dimension) to fit. Even though the full version of this case was not printed, it seemed though that the Raspberry Pi would not be able to fit so in the end it was discarded.

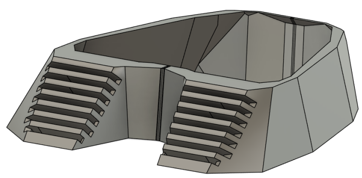


Figure 40: The skeleton of the electronics case.

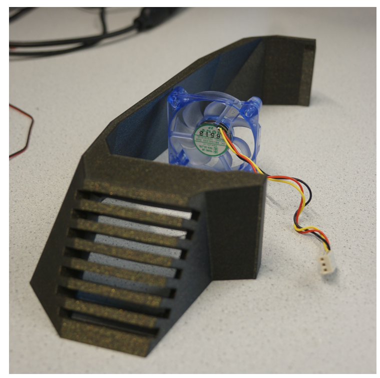


Figure 41: Half of the case 3D-printed. On a Prusa MK3S+.

Eventually, after a few more cases were created a design was found (see Fig. 42 and 43) that reflected the intentions of making it look better (of course this is very subjective) and had potential in storing the Raspberry Pi as well as hiding the electronics. It looked more streamlined yet big enough for the ventilators to fit in.

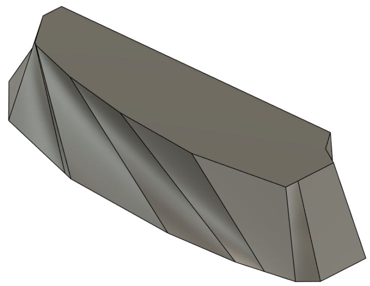


Figure 42: Half of the CAD-model after the 'Loft feature' was applied. Still bulky and some of the lines not being completely smoothed out.

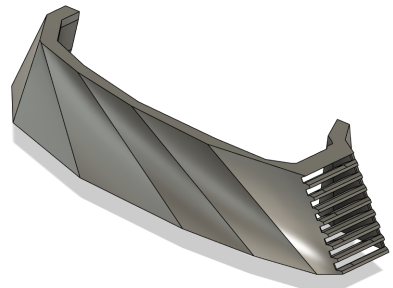


Figure 43: Half of the CAD-model with the insides hollowed out, the outside smoothed out and the details applied, such as the ventilator grill.

With this final design of the outside of the electronic case worked out, a plate to fit around the plateau and arm could be designed (as in Fig. 39, but adapted to fit the new case) for it as well as a foot could be created to seal of the complete case. Completing the case, a final CAD-model was created, see Fig 44. This CAD-model would eventually be printed and tested to see if it could actually house all of the electronics.

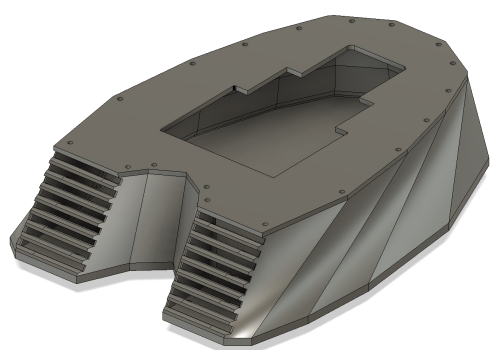


Figure 44: Final CAD-model of the more streamlined case.

5.3 Additional Features

Additional features like the Lamborghini door hinge and the backpack clip were also tried to be implemented.

5.3.1 Backpack Clip

A miniature backpack clip was printed to see how the quality of a 3D-printed backpack clip would hold up. Unfortunately, due to it being 3D-printed the quality did not hold up as to expectation and it was decided that also because it should hold a very expensive HQ camera that the current way to attach the microscope holder to the arm of the microscope was functioning well enough as it proved to be more sturdy and although it could not easily be clipped out, unscrewing a bolt was, weighing the option, not that big of a deal. More on this print can be found in Appendix B.

5.3.2 Lamborghini door hinge

Implementing a Lamborghini door-type hinge requires knowledge of how such a hinge works. A more general term for these types of hinges is a Butterfly Door, often found on luxury super cars, like a Lamborghini. Most of these hinge work mechanical, meaning they are made up of steel and such, as ofcourse these need to hold a very expensive door in place. Unfortunately, none could be found that were 3D-Printable. And lacking the knowledge to design such a mechanism from scratch the idea was dropped.

5.3.3 Lens Diaphragma

A lens diaphragma was successfully printed and tested. But not implemented. Due to it breaking and in the end not being necessary and lacking the time to print a new one, more on that in Appendix B. Even though it broke it worked quite and is something that could possibly be implemented in future development. However, with the splittable dome a way would need to be found on how to attach it between the microscope and the lens.

6 Realisation

The last step within the design process was to realize the product so it could be evaluated and used by the end-user(s). This meant finalizing the dome and case and adding the two together the complete the microscope as a whole.

6.1 The Dome

After having successfully produced multiple prototypes that provided key take-aways on how the final design of the dome should look like. The time had come to start implementing the final design that is eventually going to be evaluated with the client and end-user. Although multiple prototypes had already been created, quite a bit of work still remained to be done to arrive at a final product. Most importantly:

- Outfitting the dome (halves) with six strips of LED-lights,
- Hiding the cabling between the two layers of the dome,
- Connecting and interfacing these strips to the Pi,
- Attaching the dome to the arm.

Connecting the dome to the arm was an easy job as the dome already came with a pre-designed hinge that could fit around the arm. Moreover, the arm came with two screw holes that fitted perfectly to the hinge (as by design). And as an extra support was printed onto the hinge the dome remained perfectly in place while it was closed. In Fig. 45 it can be seen how the dome is attached to the microscope and how the halves of the dome do not get into the way of the plateau while opened.

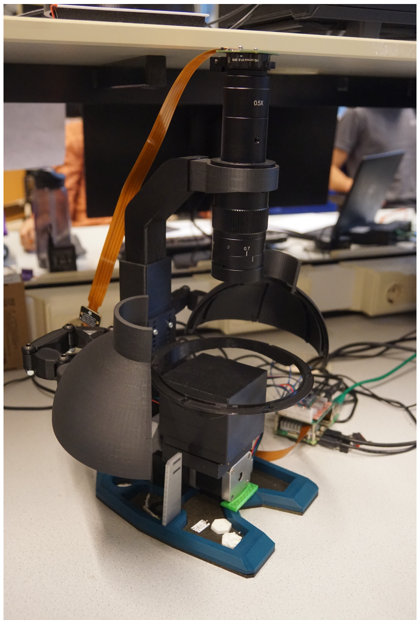


Figure 45: RTI-dome (open) attached to the arm of the microscope.

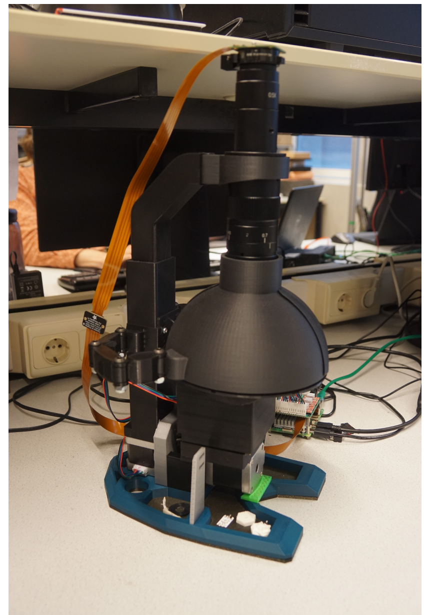


Figure 46: RTI-dome (closed) attached to the arm of the microscope.

Unfortunately, none of the LED light-strips were installed. Because at first it was believed that the original light strips from the dome by the previous duo could simply be copied and applied to the newly designed dome. However, as the dome now consisted of two halves this meant that some of the cabling had to be cut, since the previous dome consisted of just one part. This was found to be too difficult because of a lack of knowledge in soldering. Moreover, without any of the electronics installed within in the dome it was hard to determine if they would actually fit. Luckily, though during one of the prototypes it was tested to see if an LED-strip could be attached to the outer-layer of the dome with cables stuck to it. Subsequently, the inner-layer was attached and screwed onto the outer-layer with enough space in-between both layers to close properly, see Appendix B.6 for a proof-of-concept. Lastly with none of the electronics installed in the dome these could not be connected and interfaced to the Raspberry Pi. Leaving the final design of the dome with just a platform for further development.

6.2 The Case

With multiple case designs tested and printed during the specification phase a good understanding was gotten on how to design microscope cases. However it still remained a question on how to design a functional microscope case as none of these cases yet had been succesful in encompassing the micrscopes' X,Y-stage, arm, cables, electronics and most importantly the Raspberry Pi. The Raspberry Pi remained to be the problem mostly, as it was not only big but had cables sticking out on multiple sides as well that needed to also be accessible.

The furthest the design got was a mini-print of the electronics case described as the final version during the specification phase, seen in Fig. 47, 48 and 49. It was a mini-print scaled down to about halve the actual size of the print that would function as the actual case. So no actual confirmation could be given if all of the microscopes' electronics would fit in the case. However, confirmation could be given about the design and looks of the case, as well as an interpretation about the functions of the ventilation grill installed at the front. The ventilation grill was able to let through air.

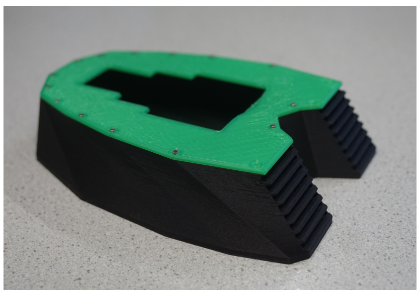


Figure 47: Mini version of the final case (side-shot).

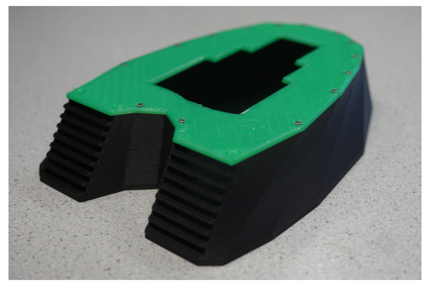


Figure 48: Mini version of the final case (front-shot).

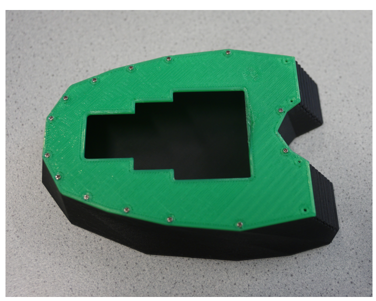


Figure 49: Mini version of the final case (top-view).

The design of the electronics case with additional plateau seemed to be pleasant to the eye. Features that were modeled in Fusion, worked well in the actual 3D-print. Like the ribbles on the side looked nice and made the design of the case very streamlined. The plateau attached to the case nicely as well, it was sturdy but still would allow for accessibility in the future if hypothetically electronics needed to be switched out. Thanks to the fact that it was screwed onto the electronics case. All in all, even though it is hard to make a comment about the functionality of the case the design of it turned out to be a success.

7 Evaluation, Conclusion and Reflection

7.1 Evaluation

One evaluation was done with the end-user / coach Carol Derla, the results of which can be found in Appendix C. The evaluation was done with the microscope in the state as it was in Fig. 45 and 46. So the newest case design was not evaluated. The focus of the evaluation was to get insights into the user-interaction and satisfaction regarding the dome and case.

Overall, the end-user seemed to be satisfied with the dome and was able to interact with it without much problems. Furthermore, the dome up till this point was functional, a non-reflective material was implemented and it made sure to be light-proof. Though the end-user commented it could be improved by taking care of tolerance during the 3D-printing process so parts would fit better in one another. The overall rating the dome got was four out of five stars, so good but still room for it to be improved.

The cases' design seemed to satisfy the end-user as well. The case was designed with thought and took care of ventilation. Moreover, it had a modern and streamlined look which was the intention though the cases' design was found to be a bit bland as well. However, it could not hides the electronics and that was a point of criticism. The overall rating the case got was also four out of five stars, so, again, good but could be better.

7.2 Conclusion

In conclusion, the project was able to enhance an open-source RTI-microscope provided by the client. By redeveloping the RTI-dome from scratch and advancing it with features to make it split open and hide cabling, while still being accessible for future improvements. Next to that the case was re-designed and given extra flair to make it more appealing to users. While also remaining accessible for future upgrades. However, no certainty could be given about the actual functionality of the case nor dome. All in all, the project remains incomplete, yet a good basis has been set for future further development and improvement of the open-source RTI-microscope.

7.3 Reflection

As mentioned, the project was not able to completely full-fill all of it set goals, nor by myself or by the end-users. In hindsight, this was probably the cause of bad planning and underestimating the work it would take to design a functioning RTI-dome and case. An RTI-dome that could be used for actual microscopic research, meaning getting it working electronically. Furthermore, underestimating the work it would take to design a microscope case around an existing platform and Raspberry Pi. While still remaining fully accessible, ventilated, big enough and also looking good at the same time. Many different prototypes were created that all tested different functionalities. However, none of these prototypes were able to enclose all of these features.

Even though, no electronics or software programming was used in this project, multiple new technologies were learned and applied to make it easier in designing quick prototypes and end-product. Such as, Fusion 360, with no previous experience as well as 3D-printing on multiple different types of printers. These were all very valuable new technologies that the project could not have done without.

Because the project is not fully complete. The focus of this thesis is now laid more on the design of a modular RTI-dome that can easily be split apart. After all the dome is not yet fully RTI-ready but the dome can easily be adapted within an RTI environment, by taking it apart and installing the light-strips. The same goes for the case it is not yet ready and at this stage quite useless, still the design worked out well and with future adjustments could probably be fit to the platform and store away the electronics. So design-wise the project was a success.

References

[1] T. E. of Encyclopædia Britannica, “Antonie van leeuwenhoek.” Britannica. https://www.britannica.com/biography/Antonie-van-Leeuwenhoek.

[2] S. Aryal, “16 types of microscopes with parts, functions, diagrams.” MicrobeNotes. https://microbenotes.com/types-of-microscopes/1-simple-microscope.

[3] O. Donker, “Hardware prototyping and instrument design of raspberry pi-based microscopy for electronics and 3d print inspection,” 2024.

[4] M. Obrocea, “Integrating image processing for enhanced examination of electronics and 3d-printed structures,” 2024.

[5] M. Eisses, “7 kijkjes onder de microscoop van antoni van leeuwenhoek.” Oneindig. https://onh.nl/verhaal/7-kijkjes-onder-de-microscoop-van-antoni-van-leeuwenhoek.

[6] Y. Goldman, “Micro-rti as a novel technology for the investigation and documentation of archaeological textiles,” *Journal of Archaeological Science: Reports*, 2018.

[7] Petersen, Joan and McLaughli, Susan, “3.1 introduction to the microscope.” LibreTexts. https://bio.libretexts.org/Courses/North$_Carolina_State_University/MB352_General_Microbiology_Laborato$

[8] H. Mytum and J. Peterson, “The application of reflectance transformation imaging (rti) in historical archaeology,” *Historical Archaeology*, 2018.

[9] “Photogrammetry – history and modern uses,” 2022. LumenForge. https://lumenandforge.com/photogrammetry-history-and-modern-uses/.

[10] T. Malzbender, D. Gelb, and H. Wolters, “Polynomial texture maps,” *ACM SIGGRAPH Computer Graphics*, 2001.

[11] G. Earl, K. Martinez, and T. Malzbender, “Archaeological applications of polynomial texture mapping: analysis, conservation and representation,” *Journal of Archaeological Science*, 2010.

[12] C. Wheatstone, “Contributions to the physiology of vision.—part the first. on some remarkable, and hitherto unobserved, phenomena of binocular vision,” *Philosophical Transactions*, 1838. Stereoscopy. https://www.stereoscopy.com/library/wheatstone-paper1838.html.

[13] “Hoe werkt focus stacking?.” CameraNu. https://www.cameranu.nl/advies/macro/focus-stacking.

[14] “Innovative imaging techniques for examination and documentation of mural paintings and historical graffiti in the catacombs of san giovanni, syracuse,” *INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE*, 2015. CHSOS. https://chsopensource.org/reflectance-transformation-imaging-rti/.

[15] C. Young, “A review of rti and an investigation into the applicability of micro-rti as a tool for the documentation and conservation of modern and contemporary paintings,” *Journal of the American Institute for Conservation*, 2020.

[16] J. Vanhauwaert, “Fotografie: De reflectance transformation imaging (rti) methode.” Paleontica. https://www.paleontica.org/article/604/Fotografie$_{D}e_{R}eflectance_{T}ransformation_{I}maging_{m}ethode.$

[17] E. Kotoula, “Study of ancient greek and roman coins using reflectance transformation imaging,” *Journal of the American Institute for Conservation*, 2020.

[18] “Introduction to reflectance transformation imaging (rti) workshop.” AICCM. https://aiccm.org.au/events/introduction-to-reflectance-transformation-imaging-rti-melbourne/.

[19] F. Bäumler, A. Koehnsen, and H. T. Tramsen, “Illuminating nature’s beauty: modular, scalable and low-cost led dome illumination system using 3d-printing technology,” *scientific reports*, 2020.

[20] J. Knapper, “Openflexure: an open-source 3d printed microscope.” FocalPlane. https://focalplane.biologists.com/2021/10/19/openflexure-an-open-source-3d-printed-microscope/.

[21] A. Mader and W. Eggink, “A design process for creative technology,” 09 2014.

[22] J. Sabhadiya, “What is 3d printing?- types and how does its work.” MechDaily. https://www.mechdaily.com/what-is-3d-printing/.

[23] C. Electronic, “Ultimaker s5 3d printer dual nozzle (dual extruder).” Conrad. https://www.conrad.com/en/p/ultimaker-s5-3d-printer-dual-nozzle-dual-extruder-1688272.html.

[24] “Meet the dodec d1: The first professional rti dome for everyone.” Dodec. https://www.dodec.io/.

[25] DIANJIEZHAO, “adjustalble microscope c-mount/ microscope stand.” ThingiVerse. https://www.thingiverse.com/thing:5567415.

[26] “Lamborghini murcielago lp640.” TheSuperCars. https://www.thesupercars.org/lamborghini-super-cars/lamborghini-murcielago/.

[27] “sourcing map 3 stück schnallen und verschlüsse kunststoff-rucksack, quick-release-schnallen 20 mm breit schwarz de.” Amazon. https://www.amazon.de/Kunststoff-Rucksack-Quick-Release-Schnallen-breit-St

[28] “Anatomy and physiology ’i’ coursework.” Blogspot. https://anatomyandphysiologycoursework.blogspot.com/2013/06/basic-microscope-anatomy-and-physiology.html.

A Interviews and Meetings

A.1 Meetings

The project actually started off meeting with our *supervisor / client*: Pep Canyelles Pericàs and our *coach / user*: Carol Derla. In these meetings over the course of a few weeks with about one meeting a week it became clearer and clearer what they expected, and their visions, for the project (microscope). They gave recommendations on where to start doing research and what upgrades could be made to the microscope, with possibility for our own inputs as well. Keypoints from these meetings were that the microscope in its current state looked quite bulky, had a limited and not very precise movement of the X,Y-Stage and was lacking in user-friendliness.

The part I took on was to improve its userfriendliness. In a later meeting with our client Carol Derla, he suggested that the RTI-Dome was lacking in user-friendliness because multiple steps have to be taken to switch out a sample. In short, the camera arm needs to go up and then the dome can be removed, the sample can be switched out, then the dome can be reapplied and needs to be recentered by matching it to a piece of tape and then lastly the camera arm needs to go down again and refocus. Therefore, he suggested attaching the dome to the arm of the microscope and re-design it so that it could be split open. Reducing the whole process to about one step.

- Remove the microscope (if attached),
- Remove the dome,
- Store dome on desk,
- Replace sample,
- Re-apply the dome,
- Re-allign the dome (based on a piece of tape),
- Attach the microscope.

In addition, the microscope case and the RTI-Dome had visible cables showing to its user and therefore needed a visual overhaul as well. So, a new design for the case was necessary. One with a dedicated space for the Raspberry PI and internal space for cables. On top of that, it needed to be modular, meaning that if in a future scenario the Raspberry PI or any of the cables had to be replaced it could easily be done by an easy mechanism to open up parts of the case. To hide the cables of the RTI-Dome it will need to consist of multiple parts: An inner layer with splits for the RTI-Lights to shine through and an outer layer to make the dome light proof and attach the RTI-Light strips on to. And also With enough space in between layers so the cables can be managed and hidden away.

B Additional 3D-Prints.

Many more small parts or whole parts and even objects were 3D-printed during the scope of this project to test out their shape, their function or even sturdyness.

B.1 Failed 3D-Print of IRIS.

An 3D-printable Iris found on ThingiVerse [19] was printed and tested successfully. However after a few uses it failed due to it not being assembled in the correct way, tape was used that ended up getting loose and rendering the IRIS useless. Nevertheless, it worked quite well the few uses it got, it was able to open and close properly.

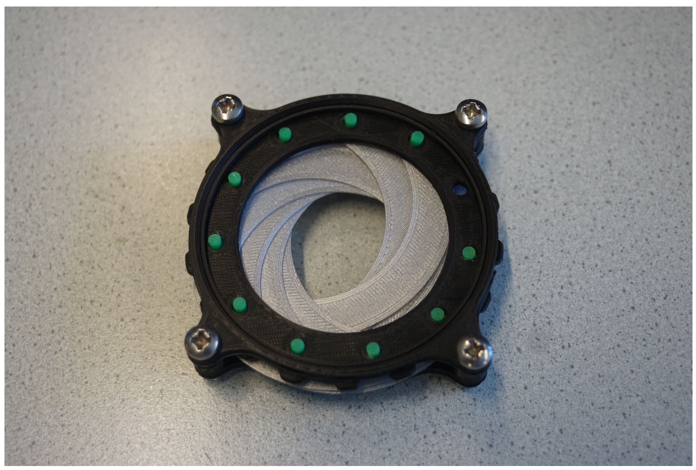


Figure 50: 3D-printed IRIS (broke).

B.2 Badly printed dome.

The dome used in prototype V3 (from Fig. 33) was printed without support and with a relatively high layer thickness (0.3 mm) to save on time, even though the dome worked out and was able to prove usable information, it was of very bad quality as can be seen in Fig. 51 and 52. The layers are very loose and not well connected. Moreover, if too much pressure was applied it would break easily.

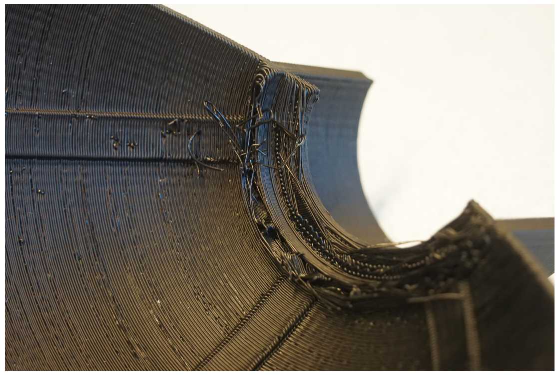


Figure 51: Print with a high layer thickness, loose parts of fillament are hanging from it.

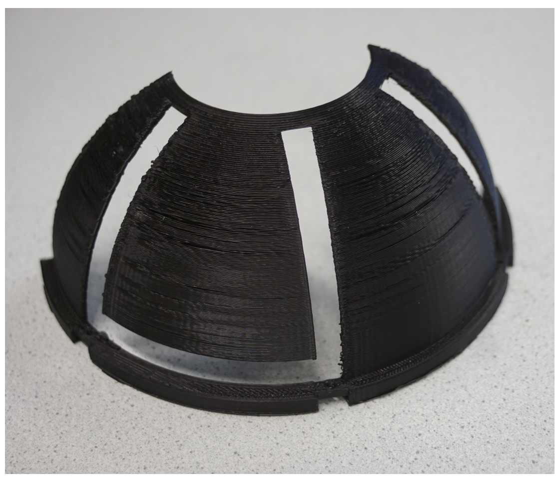


Figure 52: Inside layer of the dome with very bad quality, the layers are loose and a piece of it broke.

B.3 Additional back-up drome for further prototyping.

Carol Derla and Elia Treccani requested an additional back-up drome to be 3D-printed so it could be outfitted with a different set of LED-strips with which additional tests could be done. And a comparison could be made between what kind of LED-lights would work best.

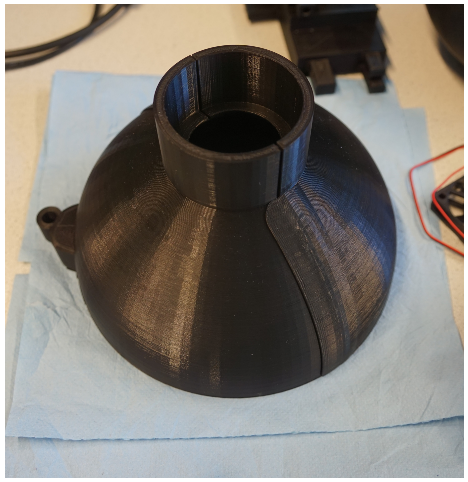


Figure 53: Additional back-up drome, printed on an Ultimaker S5.

B.4 3D-printed Raspberry PI to take measurements.

To get a better feeling of how the Raspberry Pi should fit in the case and without having to take apart the cabling of the actual working Raspberry Pi, a replica of it was created in Fusion 360 with the exact same measurements and some of the key cabling attached to it. So it could be fitted and adjusted easily with prototypes of the case. This replica Raspberry Pi made it easier to find a good position for it next to the X,Y-Stage, from which a case could be designed around.

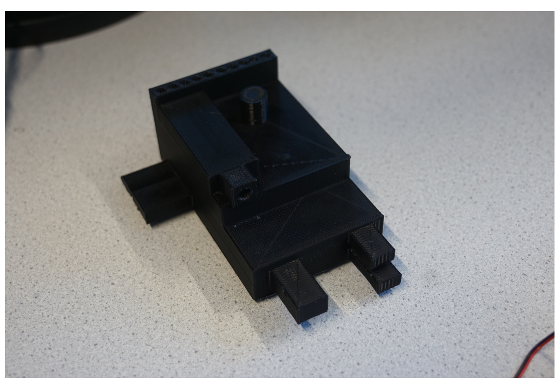


Figure 54: Replica Raspberry Pi.

B.5 Backpack Clip.

This backpack clip was printed by the technicians of RAM-Lab at the University of Twente on a Bambulab 3D-printer and was taken from ThingiVerse (link: https://www.thingiverse.com/thing:80812). The backpack clip meant to serve as a prove of concept, it worked, however it was not strong enough and did not really click like an actual backpack clip. The idea was to replace the arm holding mechanism with the left side of the backpack clip as seen in Fig. 56. Moreover, the ring around the microscope to keep it it in place would instead of a bolt have a mechanism similar to the right-side of the backpack clip as, again, seen in Fig. 56. So the ring could easily be switched out to hold another type of camera.

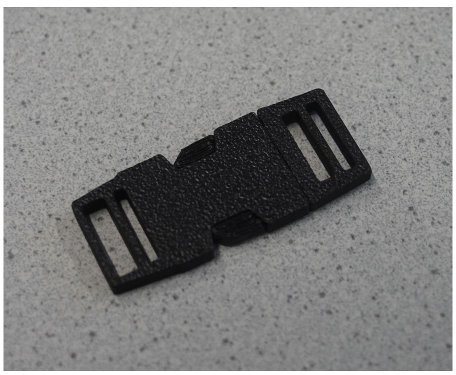


Figure 55: Backpack Clip (closed)

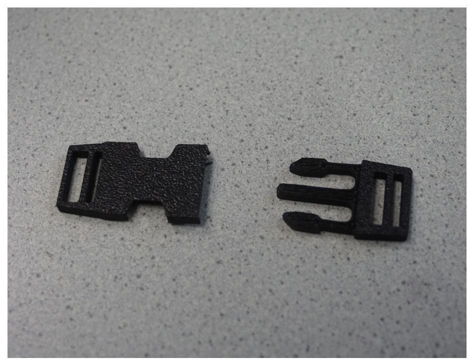


Figure 56: Backpack Clip (open)

B.6 Quarter of dome printed to test if LED-strips would between halves.

One prototype of the dome was printed at about two-thirds of the actual dome halve. Specifically, to test if electronics (non-working), like the LED-strips with cables attached could fit inbetween the halves. Moreover, if the cables connecting these strips could be tucked away in the rest of the dome without overlapping the LED-strips.

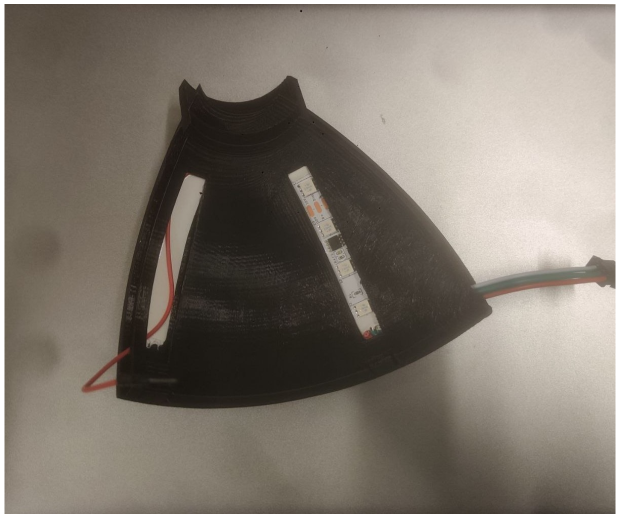


Figure 57: Low-quality picture taken on smartphone of electronic fitting test-print of dome halves (inner and outer).

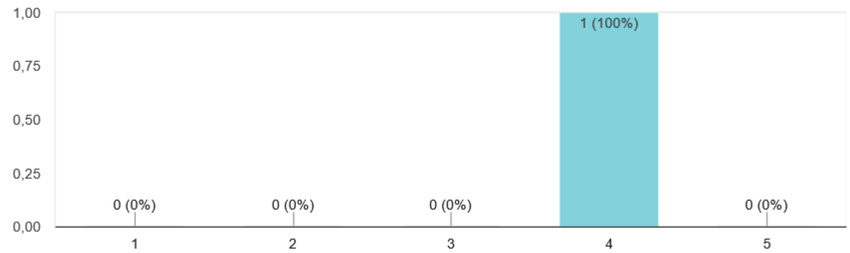
C Evaluation Form

An evaluation was done with the end-user / coach Carol Derla, the results of which can be seen on the next few pages. The evaluation form was setup in google forms as this provided an easy way to make these types of online forms that can easily be shared via e-mail. A link to the form can be found here, note though it is closed so no responses are accepted anymore: https://forms.gle/XZQ4yS4nPfbn4ncA7.

The new design of the case is pleasing to the eye.

Diagram kopiëren

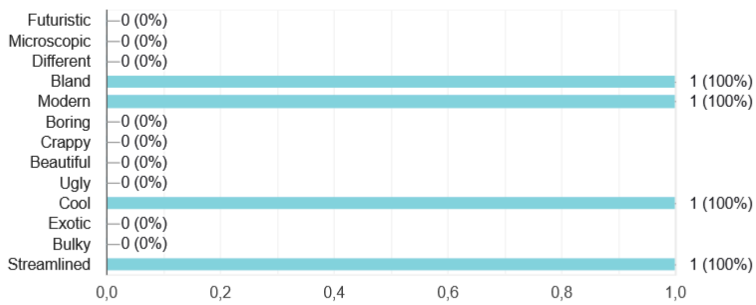
1 antwoord



How would you describe the overall look of the case?

Diagram kopiëren

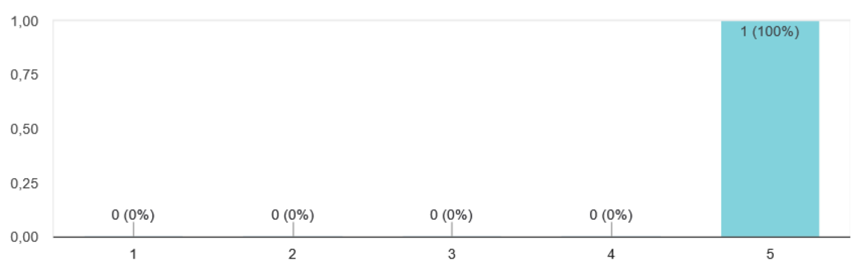
1 antwoord



The case is able to provide enough ventilation to the Raspberry Pi.

Diagram kopiëren

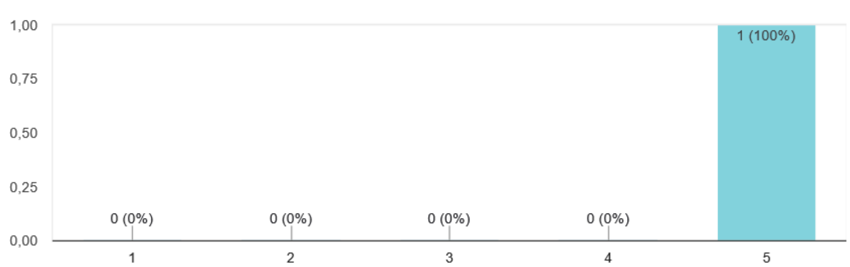
1 antwoord



The case is designed with thought.

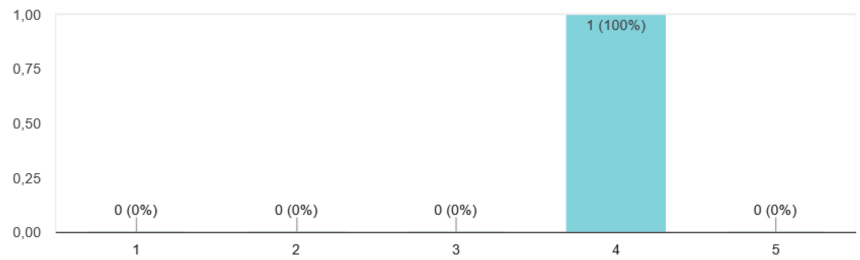
Diagram kopiëren

1 antwoord



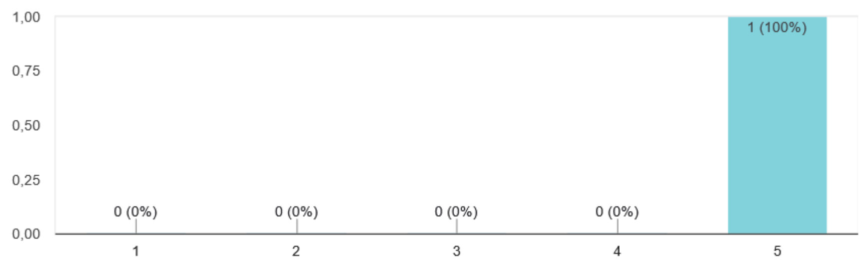
The case is easily accessible for future adjustments.

1 antwoord



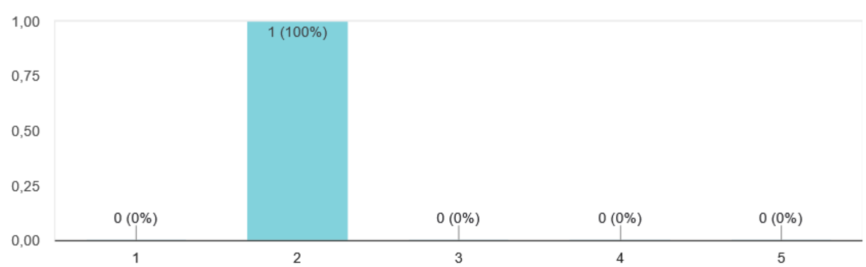
The case fits well with the X,Y-Stage (does not get in the way of it etc.).

1 antwoord



The case hides the electronics well.

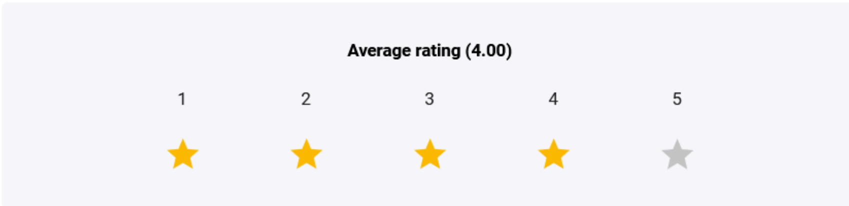
1 antwoord

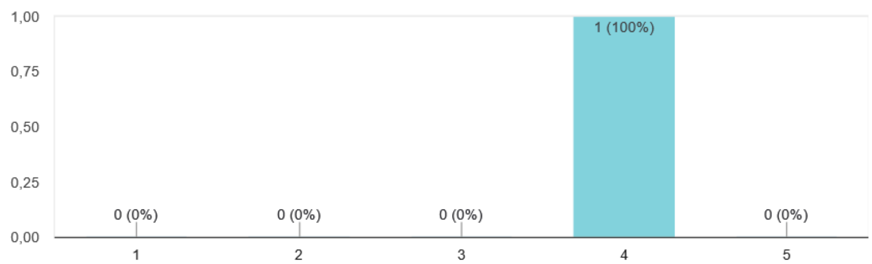


How would you rate the overall case (with the previous questions in mind)?

Diagram kopiëren

1 antwoord





Any additional remarks about the case?

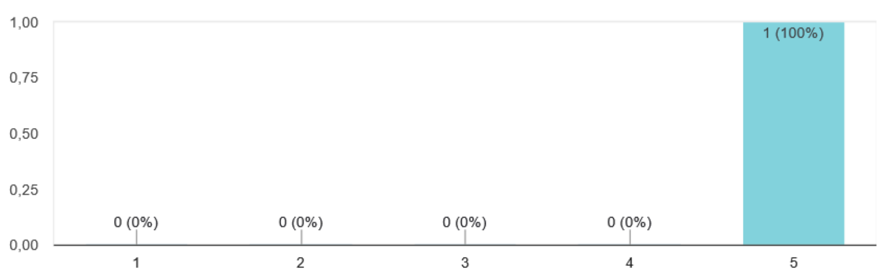
1 antwoord

It lacks on the cable management aspect and 3D printing optimisation regarding post print assembly. Aspect wise it fits the purpose as well as the air ventilation system for the electronics.

The dome splits in an user intuitive way.

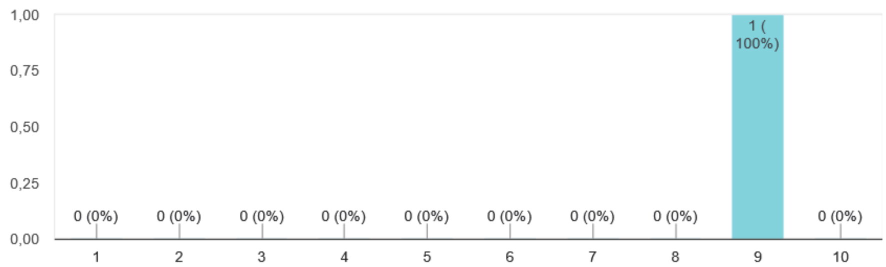
Diagram kopiëren

1 antwoord



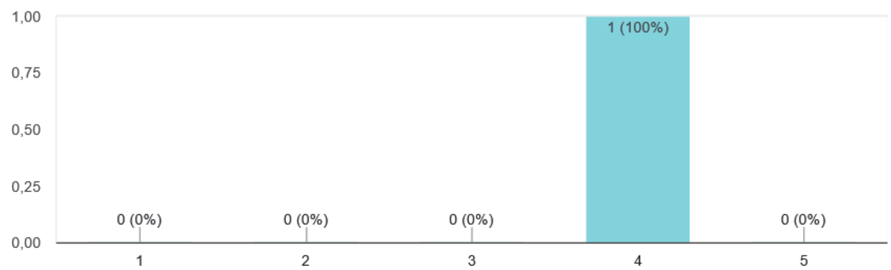
The new dome is an improvement to the previous dome (with 5 being similar).

1 antwoord



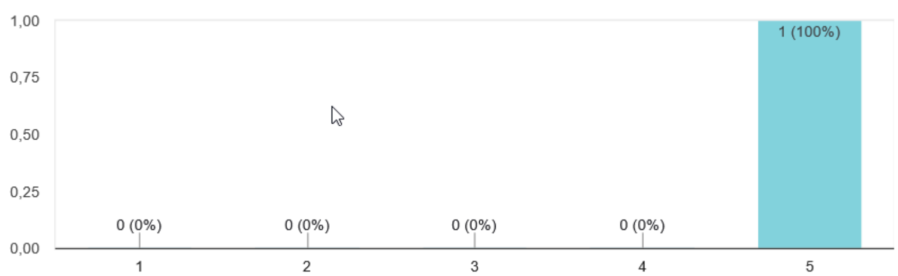
The dome can easily be taken apart for future improvements.

1 antwoord



The dome is RTI (Reflective Transformative Imaging) ready.

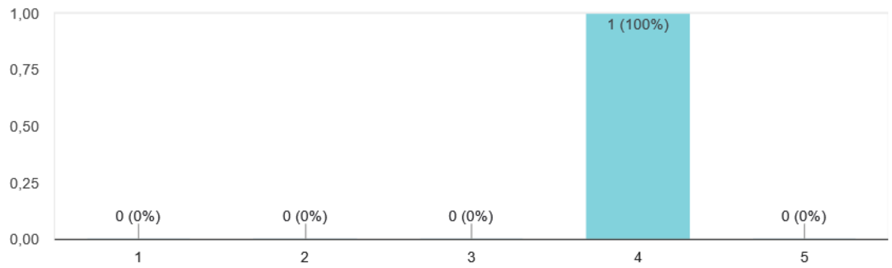
1 antwoord



The dome fits well to the rest of the microscope (take in mind how it is attached to the arm).

Diagram kopiëren

1 antwoord



The material of the dome makes sure not reflect any light.

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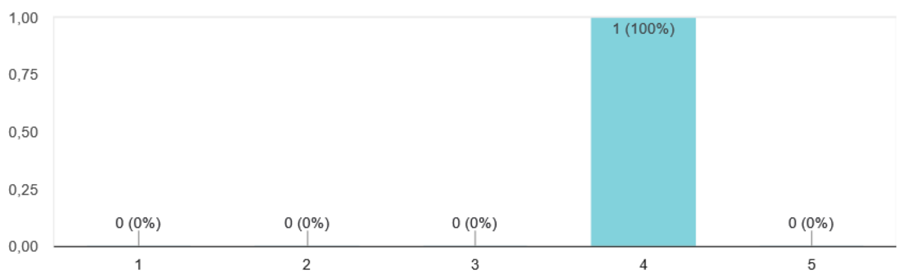

The dome is lightproof when closed.

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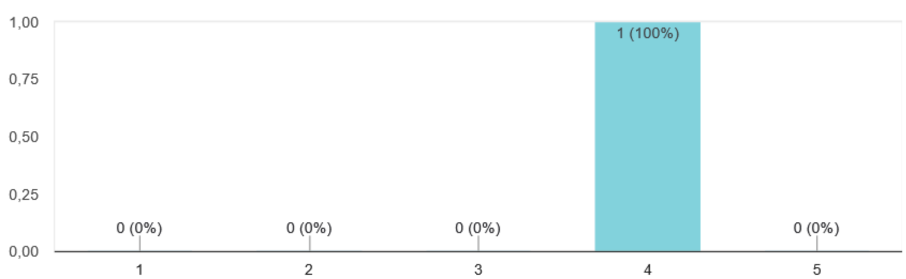

The dome looks professional and can be used out in the fields.

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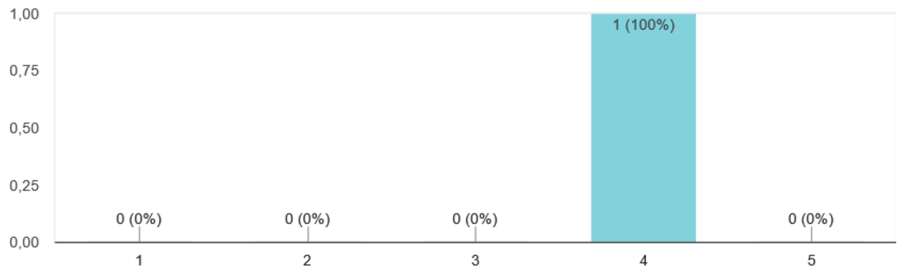

How would you rate the overall dome (with the previous points in mind)?

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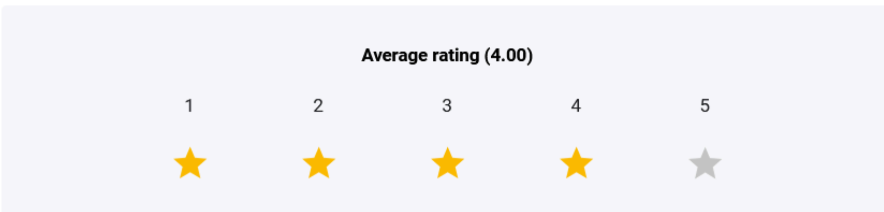

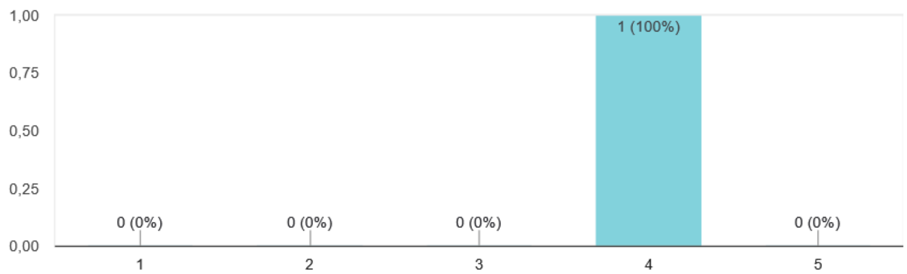

Any additional remarks about the dome?

1 antwoord

The dome design is well thought out, together with the stand that was improved to prevent sagging. Some 3D printing optimisation for improved fitting of parts resulting in smoother operation of the dome (opening and closing) is still needed. The hinge design can be improved to have a more defined trajectory compared to the current design of multiple hinges that result in a large (unneeded) range of motion.