H3D-VISIOnAIR Project Report

Course: MEC-E3001 - Product Development Project
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Introduction

Brief

The Challenge: “Developing a Near-Infrared Light Source, having the most even intensity possible throughout the spectrum of 700-1000 nm.”

“Developing a prototype of a multifunctional lamp source to be used in a multi-spectral camera, automatically proposes the optimal light settings and is capable of measuring the actual spectrum that is offered. The light source requires specific intensity, spectrum, and light distribution characteristics. Such a light source is currently not available on the market. A fully functional prototype would potentially be a stand-alone product the consortium would bring to the market. The capabilities of the light source can be inspired by the Osa Opto Light.”

Re-framing the Brief

Discussions with the representatives from the H3D-VISIOnAIR project framed the problem more. We decided it was enough to reach 1000 nm wavelengths for our project. In addition, the spectrum should be as uniform as possible.
After careful evaluation, it was determined that a standalone product with a multifunctional lamp source capable of automatically suggesting optimal light settings was beyond the capabilities of our team and could not be achieved. As a result, the project was re-framed, and the decision was made to focus solely on developing a near-infrared light source with the highest possible evenness in the spectrum of 700-1000 nm.

Client

H3D-VISIOnAIR defined the project. They are a consortium in the Netherlands and have been secured by ATTRACT and EU funding. The consortium comprises i-Med Technology, Quest Medical Imaging, Maastricht University Medical Centre/ University Maastricht, Amsterdam University Medical Centre and the University of Twente. Together with IMEC Netherlands, they aim to develop an AR headset for surgeons that can differentiate different tissues that are otherwise indistinguishable by the human eye.

European Commission's Horizon 2020 (H2020) programme funds ATTRACT project to develop breakthrough technologies for science and society. The goal is to unite researchers and industrial communities to build and lead the next generation of detection and imaging technologies. By creating products, services, companies and jobs, the ATTRACT projects help to improve people's lives and revamp Europe's economy[1].
The ATTRACT project is divided into two phases. Phase one has funded 170 breakthrough technologies, and H3D-VISIOnAIR was one of those. The process targeted phase 1 to concepts in the early stages of the innovation value chain (Technology Readiness levels 1 to 4, see Figure1). Its focus was identifying and initiating interlinks among a community of actors. In 2019, the H3D-VISIOnAIR already completed TRL 3. The ATTRACT phase two will focus on consolidating the interlinks among the communities. Reducing risks toward the market is the goal of the second phase.

Scenario

The idea behind the technology is to shorten the surgery time and make surgical operations safer and less stressful for surgeons and patients. In addition, the technology can be used as a teaching tool for potential doctors and surgeons.

The technology the H3D-VISIOnAIR is using requires light beyond the visible spectrum to differentiate the tissues. **Our Product Development Project aims to produce a lighting solution that would be implementable for the next H3D-VISIOnAIR prototype and could create a uniform spectrum of light between 700 and 1000 nm.** The goal of the prototyping section of the project is to achieve TRL 6. Figure 2 shows the Gantt chart which gives the team an overall understanding of the project phases with specific deadlines.

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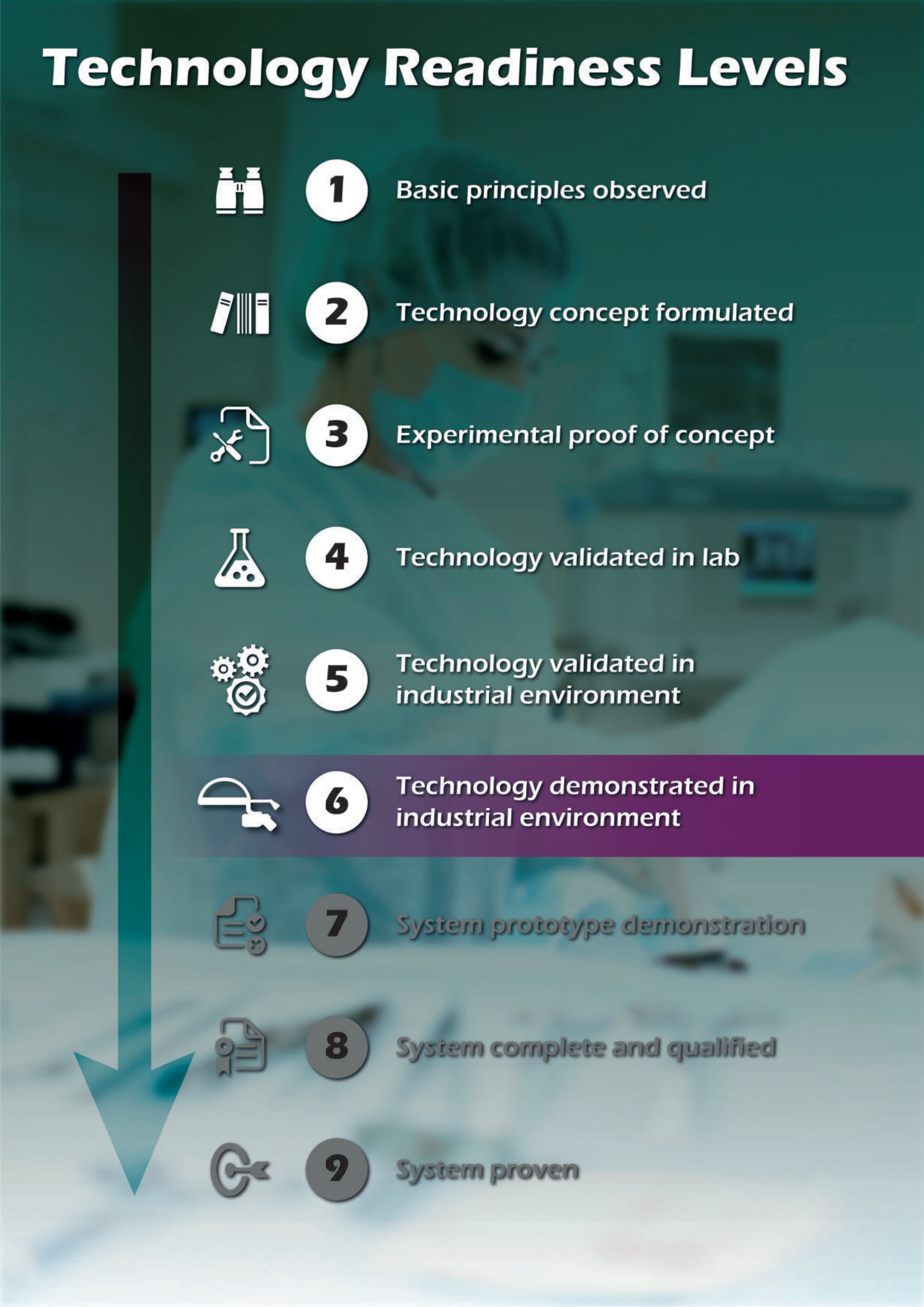
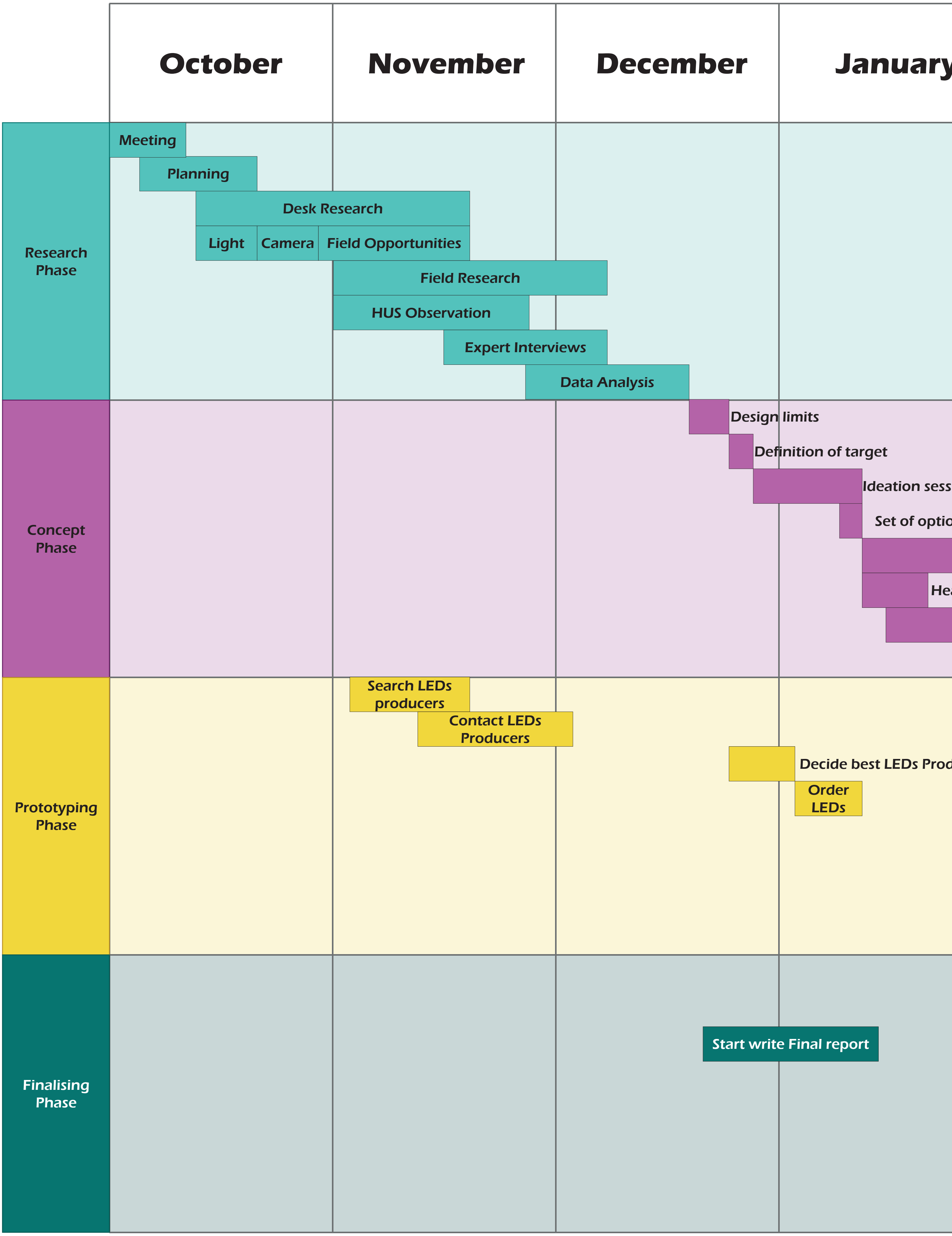
[1] *The Technology Readiness Levels were established by NASA and introduced in European Commission's research and innovation projects in 2020.*

Technology Readiness Levels



1. Basic principles observed
2. Technology concept formulated
3. Experimental proof of concept
4. Technology validated in lab
5. Technology validated in industrial environment
6. **Technology demonstrated in industrial environment**
7. System prototype demonstration
8. System complete and qualified
9. System proven


October
November
December
January
Research Phase
Meeting
Planning
Desk Research
Light
Camera
Field Opportunities
Field Research
HUS Observation
Expert Interviews
Data Analysis
Concept Phase
Design limits
Definition of target
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Contact LEDs Producers
Decide best LEDs Prod
Order LEDs
Finalising Phase
Start write Final report

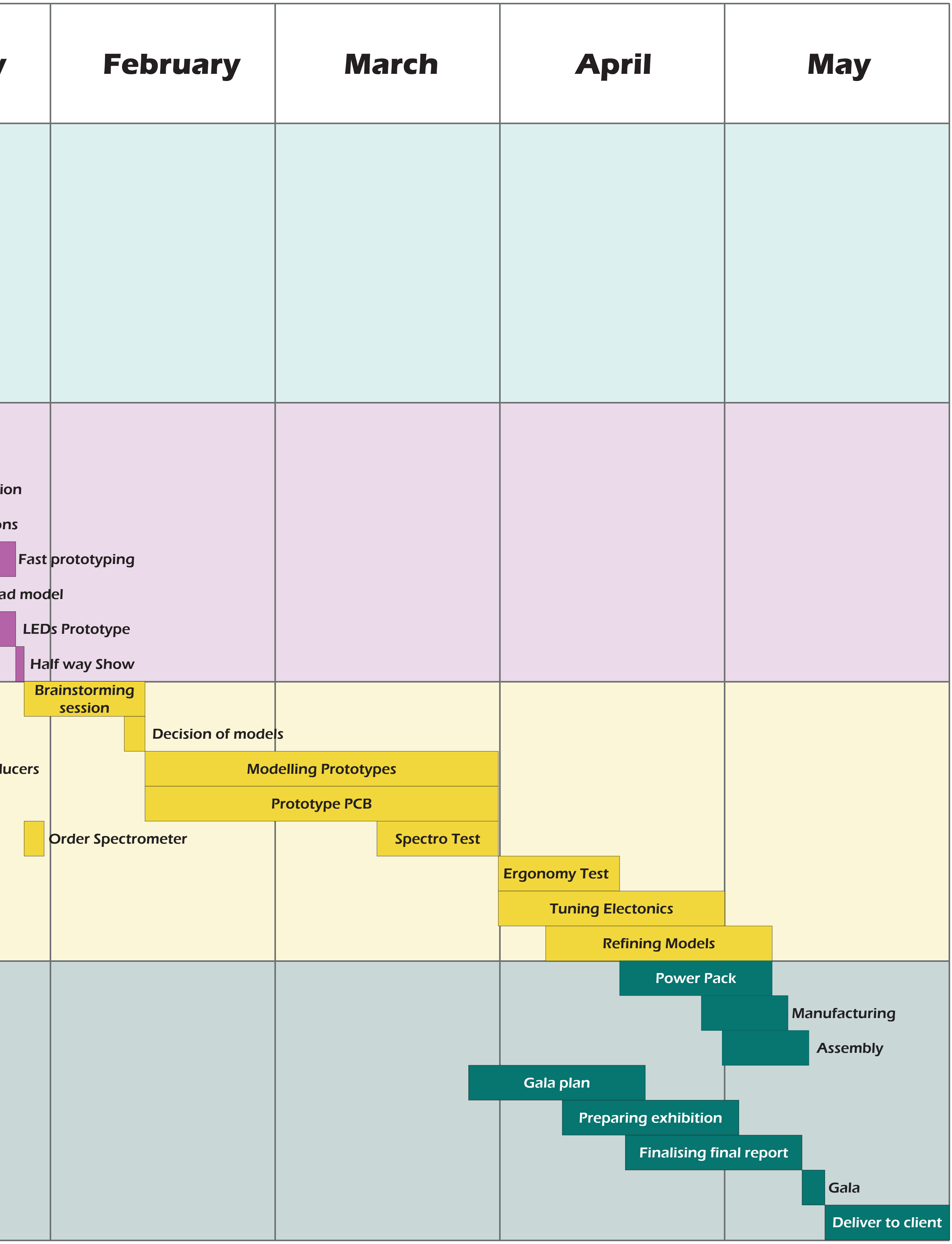


Figure 2: Team HAREVA's Gantt chart

Methods

Throughout the project, our team used various techniques to achieve the desired results. More theoretical approaches were applied in the project's first half, and practical methods were later applied. The primary method used from the beginning of the project is the Double Diamond process model (Figure 3), by which we defined the project phases. During regular online and in-person meetings, idea generation, brainstorming, prototyping, and debating were effective methods for sharing opinions. Moreover, interviews with surgeons and experts in the field were conducted to understand different stakeholders' points of view. A complete list of applied methods are listed below with a brief description.

Research phase methods

Desktop Research: We initially relied on desktop research to obtain information. However, as the project progressed, we incorporated additional processes, such as interviews with experts and meetings with sponsors to gather more comprehensive and diverse data.

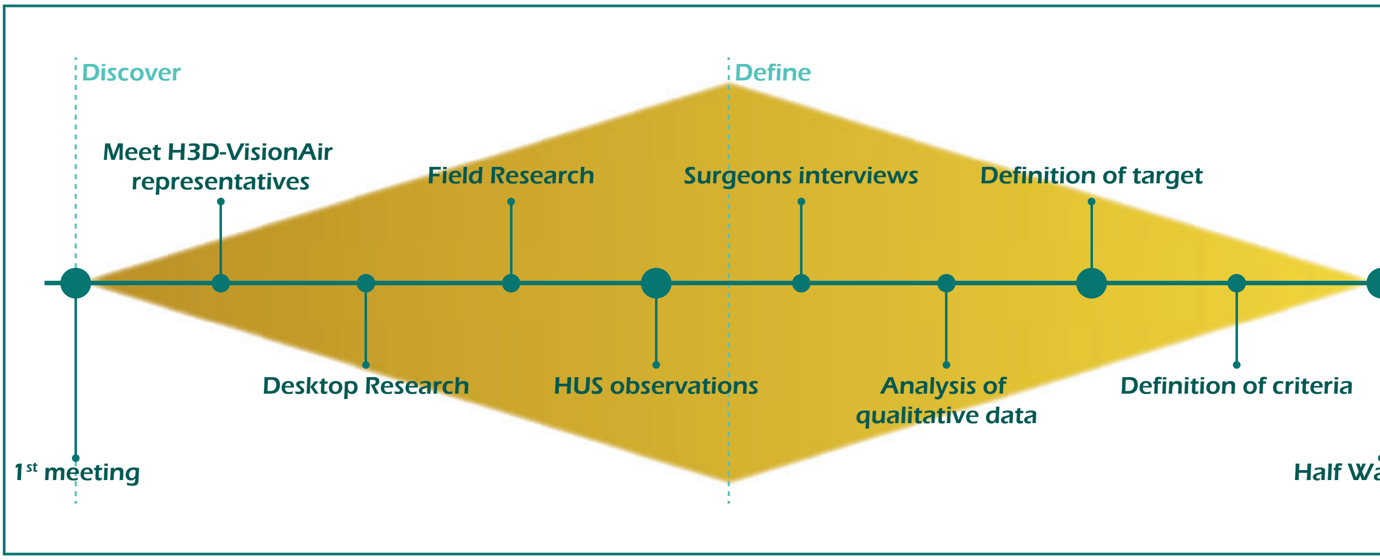


Figure 3: Project's Double Diamond model

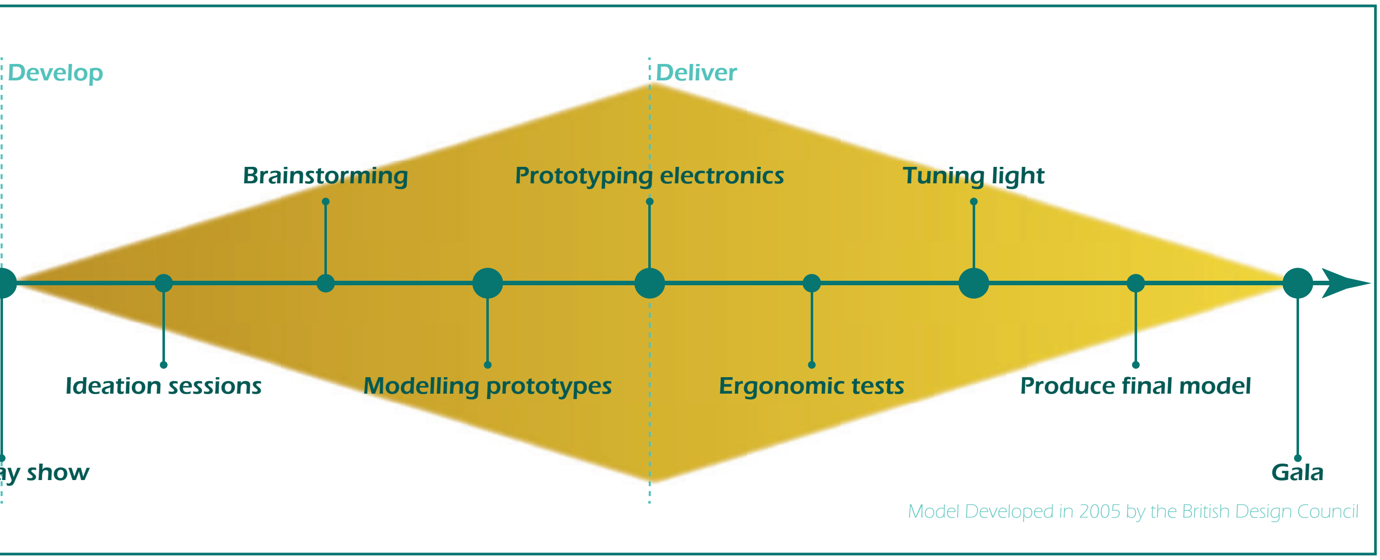
Interviewing and Ethnographic Observation: Different interviews with experts were organised during the research and manufacturing phases. To develop a precise understanding of the atmosphere the final device would function, approximately 1.5 months after the start of the project, the team visited HUS (Helsingin ja Uudenmaan sairaanhoitopiir (Hospital District of Helsinki and Uusimaa)) to observe real-time operations and interview surgeons.

Ideation, Brainstorming, and Mind Mapping: To define the required steps of the projects and find the right solution to the challenges, brainstorming and mind mapping was central to our approach.

Development methods

Modelling and Designing: Although the project aimed to develop a light system, we also focused on the headset and, more specifically, the component to which the light is attached. Design and modelling of the product were done in Autodesk Fusion 360.

Prototyping and Testing: The project's second phase focused extensively on prototyping testing. They served as critical milestones in the project as we could translate our ideas into tangible representations, allowing us to test and refine our concepts relatively.



Research

This chapter provides the most crucial knowledge obtained before the development phase. The information in this chapter has been collected through a combination of desk and field research and covers the cameras, lights, possible applications, PD6 and HUS, respectively.

Cameras

Since our light will be used in conjunction with a hyperspectral camera, it was first essential to look into different hyperspectral cameras currently on the market. The key takeaways from the camera research were:

- Most cameras only exceed 1000 nm. This seems to be a limit on the commercial CMOS (Complementary Metal Oxide Semiconductor) sensors used on many of the cameras.
- Most cameras have a low frame rate (< 20 fps).
- Most cameras have relatively low resolution (about 500 x 500 px). The maximum found on the market was 1000 x 1000 px without going into speciality laboratory equipment.
- There are many small and compact cameras available, slightly larger compared to an action camera like GoPro.
- Cameras create vast loads of data that are often immediately offloaded from the camera to a computer. High-speed connections like USB and Ethernet were the most common interfaces for doing this.

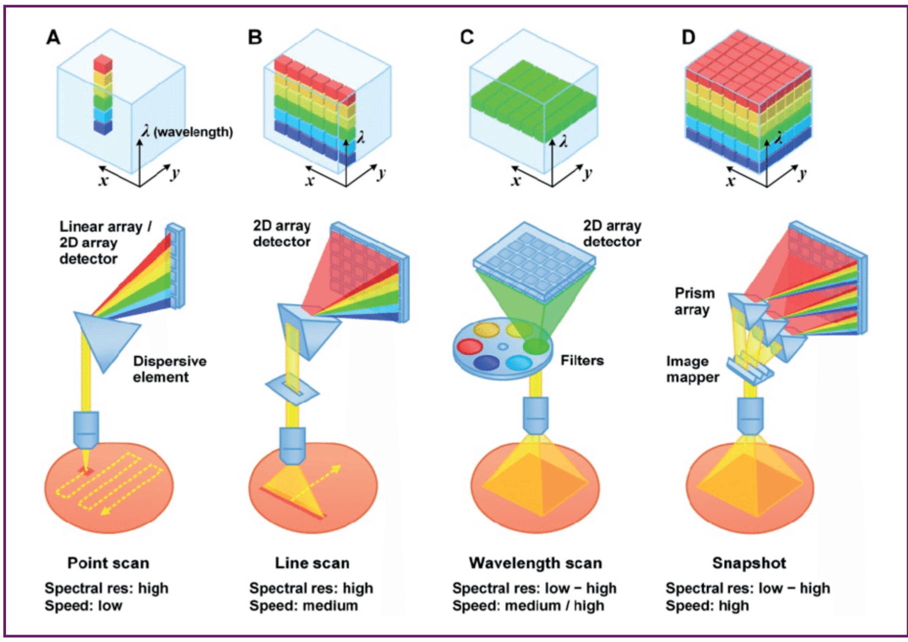


Figure 4: Typical (hyper) spectral imaging approaches. (A) Point scan. (B) Line scan (i.e. "pushbroom"). (C) Wavelength scan. (D) Snapshot.

Lights

Because the standard hyperspectral cameras only go up to 1000 nm, we decided to use that as the upper limit for our lighting research. Figure 5 illustrates the visible and invisible spectrum of light.
Since we do not need to illuminate the visible spectrum, we chose a lower limit of 750 nm for the light. Many Near Infrared (NIR) lighting solutions are available on the market but are generally bigger-sized area lights. The lights typically aim at factory quality control stations where products are illuminated and analysed.

We researched different lighting technologies, but in the end, LEDs were deemed the most promising. The most significant factor in choosing LED technology was the high efficiency, which makes the thermal loads of a powerful and small light easier to manage. Currently, only a handful of manufacturers of high-powered LEDs operate in the near-infrared region (750-1000 nm). We needed these high-power SMD LEDs since the light needs to be as small and lightweight as possible to work well in a medical headset. We identified three possible LED solutions:

1. Use only broadband LEDs that cover the visible range and up to 1000 nm.
2. Use a mix of broadband and single-wavelength LEDs.
3. Use only single-wavelength LEDs in various wavelengths.

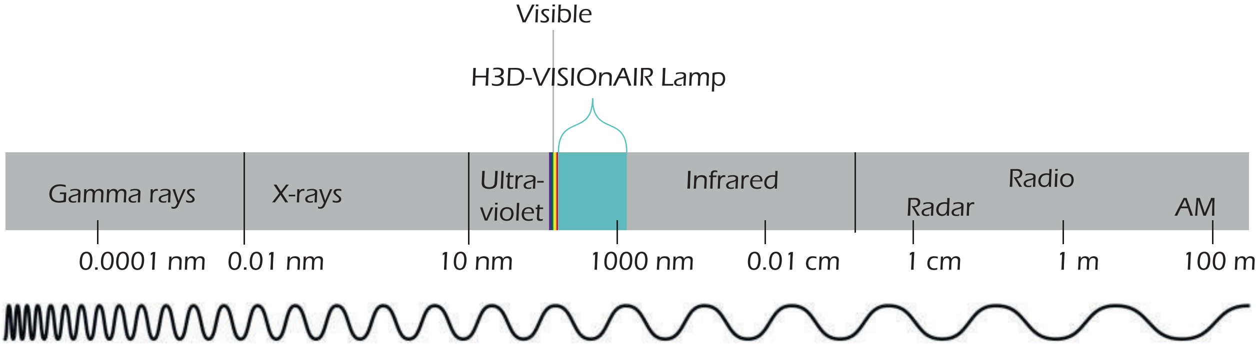


Figure 5: Division of light spectrum

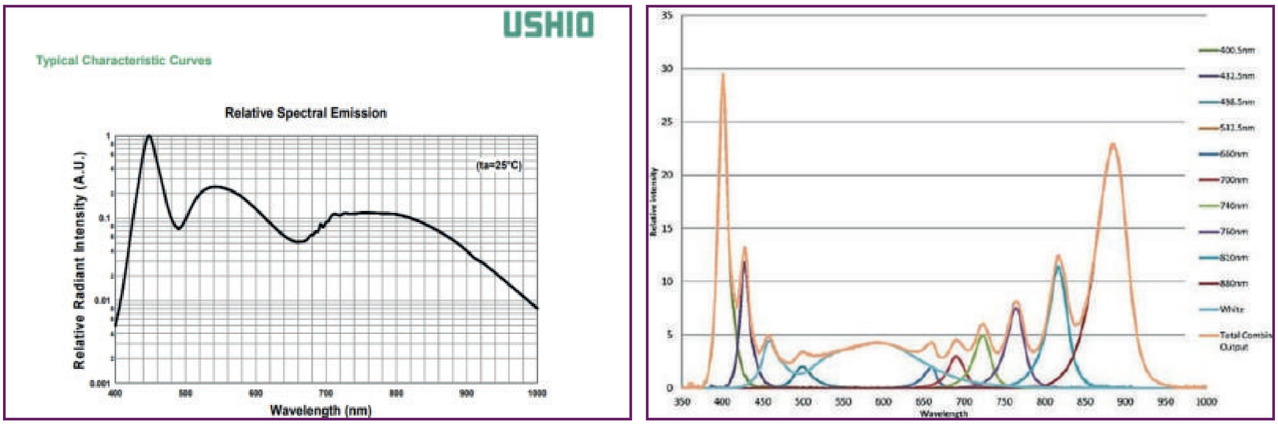


Figure 6: Right –the spectrum of the Ushio SMBBIR45A-1100-02 broadband LED (example of solution 1), Left -The spectrum of a Prophotonics COBRA HyperSpec LED line light (example of solution 3).

Some manufacturers we identified that provide suitable high-powered LEDs were Marubeni, Osa-Opto, and Ushio. After asking for quotes, we unsurprisingly only got a response from one manufacturer. Since these are large-volume manufacturers with big minimum order quotas, we were understandably not attractive to them from a business standpoint. Fortunately, Ushio was willing to work with us as a supplier and supply our R&D with small quantities of their different wavelength LEDs.

Without the help of Ushio, this project would've been significantly reduced in scope. Traditional order quotas in the hundreds or thousands would have made the whole project cost prohibitive. If we had to buy a hundred LEDs of each wavelength, we could've only bought one or two wavelengths instead of the fourteen we had in this project. Ushio's willingness to ship a batch of LEDs smaller than their usual minimum order quantity made it possible for us to develop a very versatile light. Ushio also had a reasonable lead time and good stock levels at the time of our order. Long lead times stretching from months to a year have been commonplace in the semiconductor industry post-Covid, and had we experienced that, the project would not have been possible.

Possible applications

Except for the medical field, a light system that covers the invisible spectrum can have potential applications in different areas. One could be an industrial inspection. Such an illumination system can be used for inspecting parts and machinery that are difficult to see with the naked eye. It can help detect defects or flaws in products that are not visible under normal light, allowing for more accurate and efficient inspections.

Another possible application could be agriculture. A light system that covers the invisible spectrum can monitor crop health and identify specific diseases or pests. For example, it can detect plant stress caused by water or nutrient deficiencies or identify areas where pathogens infect crops. Moreover, a light system that covers the invisible spectrum can be used for environmental monitoring, for example, to monitor air and water quality by detecting contaminants that are not visible under normal light. Another possible application of this system can be forensics. It can be used in forensic investigations to identify trace evidence such as blood or fingerprints. It can also help identify counterfeit money or documents by revealing hidden security features. However, it must be noted that each application's system specifications and other essential components would differ. Since they are necessary fields, developing the whole system requires diligent study.

Product Development in 6 hours

PD6, or "Product Development in 6 hours", was an event on November 7th. All the teams and their sponsors had to work on a topic together for six hours. The cases were the professor's proposed questions about each team's project. The result of each group work had to be presented in 5 minutes, and the presentation could have any format including but not limited to: PowerPoints, videos, speech, photos, etc.

The question for our team was: "**Demonstrate how augmented vision helps surgeons in their work**". After brainstorming, we divided the tasks between presentation, research, and prototyping. We defined the exhibition's structure around a fake and real blood demonstration.

The animal blood was purchased from a grocery store. The fake blood was created from scratch. We tried multiple ingredients but had difficulty matching the viscosity and colour of the actual blood. The first attempt used water, corn syrup, and red food colouring. The colour was very different from real blood, and adding more food colouring did not solve the issue. The second time around, we used a thick red juice concentrate from Vimto. The Vimto gets its blood-like colour from a black carrot, and after diluting the juice with water, the colour was very similar to real blood.

With the two blood samples photographed, the audience was invited to guess from the pictures which was the real blood. Many people chose wrong as we expected. To prove our point, we showed the spectral graphs of the two pictures. With nothing but data extracted from two regular pictures using Matlab, we could decisively determine which sample was the real blood.

To expand on the medical possibilities of spectral imaging, we showed videos on how AR in surgical cameras can differentiate between different tissues and organs. The main objective was to show and compare the doctor's visuals before and after AR so the audience could understand the problem and the solution.

Ultimately, our team's presentation was the best of the day. The main reasoning by the teaching staff was the clear communication and demonstration of the difficulty of visually identifying different tissue types, how AR can provide that information, and the patient health benefits of doing so.

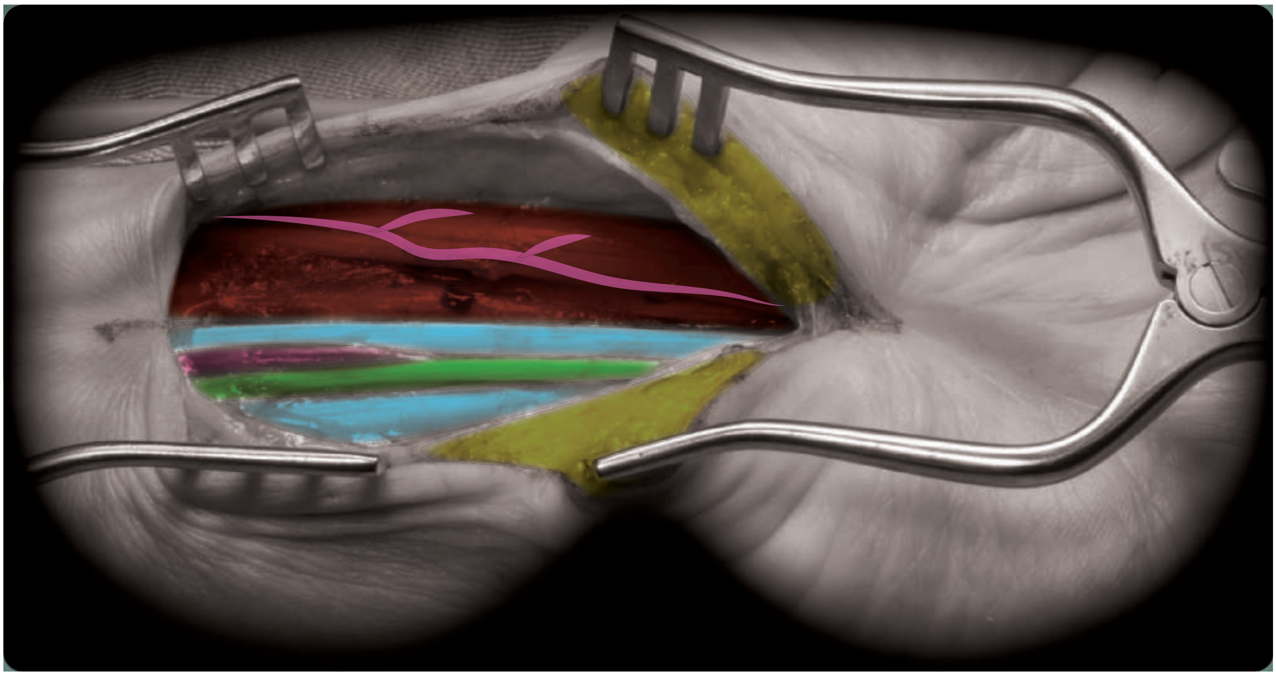


Figure 7: One of the visuals used in PD6 illustrates how the final system will differentiate the organs.

Ethnographic Observation in HUS

The reasons why we decided to spend time in real-life observations are multiple and varied. Firstly, our client had already specified that they were working on a new technology to improve surgical operations. We needed to understand the environment in which our product was to be inserted. Additionally, we wanted to identify any potential impact on how medical professionals and patients would receive and use our creativity and any potential issues arising from its implementation. Furthermore, it was essential for us to assess the impact of our product on the cost, efficiency and quality of healthcare services. Thus, real-life observations were the most effective way of gathering all the necessary research and data regarding our product and its integration within the medical field.

With our professor's help, we contacted the University Hospital of Helsinki. They are responsible for many medical student training in the Finnish capital, so they are accustomed to having students in operating rooms. After introducing ourselves, we were in contact with a pulmonary surgeon who permitted us to observe three different operations:

- Laparoscopy (e.g. Karl Storz)
- Open Surgery
- Thoracoscopy (Video-Assisted Thoracoscopic Surgery, Intuitive robotic-Davinci)

All three aimed to remove lung cancers from three different patients.

Figure 8: Laparascopic Surgery, surgeons have specific glasses of a 3D vision looking at the screen.

Before observing medical operations, we studied the three types of surgery to gain a comprehensive overview of what we could expect. As part of our preparations, we held a brainstorming session to identify the specific details we wanted to observe (Appendix 1) and the questions we wanted to ask surgeons.

We also prepared consent sheets and other necessary information for the surgeons (Appendix 2) to ensure we had all documents needed to conduct ethical research that respected the privacy of those who assisted us.

The three observations we conducted in November 2022 were each approximately four hours long. We spent twelve hours in the operating room, taking note of the environment, the objects and machines, and the work team dynamics. It was remarkable to see how surgeons, anesthesiologists, and nurses interact with each other, covering their roles and allowing smooth operation progress. Even though each operation was unique, the context and the interactions between the people involved were strikingly similar. We noted it keenly during our observations, which was a precious experience.

We also conducted two in-depth interviews with the leading surgeons to understand the potential of H3D-VisionAir developments and how they might benefit from their use (Appendix 1). After our observations, we wanted to gain a clearer insight into what we had seen and asked for further clarification; this was done during our interviews, to ensure that we had a complete understanding of the situation. The surgeons provided valuable information that was both helpful to our research.

We attempted to include drawings of how surgeons would ideally like to view augmented reality (AR) through the glasses our client was designing. To this end, we prepared several visual materials comprising images of operations with visible organs and anatomies (Appendix 3). We then wanted to ask the surgeons how the AR should appear to apply to them. We aimed to dedicate 10 minutes of the interviews to drawing on the papers. Unfortunately, we were interrupted by emergencies both times, and thus, we could not get this information.

Figure 9: Close-up to the Open Surgery, the surgeon wears glasses and head-lamp for an additional light spot.

Ethnographic Observation Findings

We categorised the key points relevant to our project development to summarise what we learned from these observations.

On surgeries

- There are several roles within the working team: the surgeon, the assistant surgeon, the anesthesiologist, the assistant anesthesiologist, the OR nurse, and numerous nurses in support.
- The room is equipped with everything you might need.
- The work area is divided by a curtain. On one side, surgeons and nurses work at a frenetic pace. Conversely, anaesthetists monitor the patient's vital values in a calmer atmosphere.
- The patient is covered with sterile sheets for hygienic purposes. Only the area to be operated on is visible.
- The language used for both speaking and labelling is the national language.
- The type of intervention is chosen by comparing different parameters, so there is no single technique or tool for the same operation. Generally, interventions requiring sophisticated machinery take less time than open surgery, allowing for the use of technologies not optimised for long periods.
- Open surgeries are a fraction (about 10 - 20%) of the surgeries. The prevalence is of minimally invasive surgeries.
- Specific body characteristics are called "landmarks" because they help the surgeon identify tissue and body parts.

On Lights

- Every operating room is equipped with two ceiling lights. The first is more for the ambient, far from the surgical scene, and not movable. The second has handles and arms. It is movable concerning what is needed for the surgical scene.
- In Open Surgery, the surgeon wears a light headset connected to a pocket battery. It is adjusted to highlight the same focus as magnifiers glasses. The diameter of the light on the surface is around 15 cm.
- A less common option is a fibre-optic headlight, accompanied by a bulky generator restricting the doctor's mobility. However, it has the benefit of providing brighter and more powerful light.
- For Laparoscopy and VAT Surgery, they use an endoscope provided with two spotlights and two cameras. Most controls are on the handle, but they can be partially remote-controlled.


da Vinci Xi
SURGICAL SYSTEM
8mm
0°


3

On Cameras

- Open surgery: The camera positioned on the lamp is connected to the room's screens. The projection allows the crew to see what is happening, but the surgeon or the assistants do not use it. It can zoom but cannot turn. To adjust it, they need to move the light. The head covers the camera recording when the doctor needs to get closer to the organ.
- The camera's recording is always stable.
- For Laparoscopy and VAT Surgery: the camera can be adjusted with zoom and little turnings, but it is fixed.

On Vision

- Laparoscopy: The surgeon looks at screens for the whole surgery. S/he wears special glasses to look at the ICG in 3D. Screens surround the scenario so also assistants can see.
- Open Surgery: The surgeon looks directly at the uncovered organs. S/he wears Loupes with magnified lenses for the details.
- Thoracoscopy: The surgeon looks through the robot in 3D vision. The record comes from the endoscope camera attached to a second machine. The two devices can be quite far from each other, so they need an assistant near the patient's body to manually adjust specific parameters or tools of the robot.

The **opportunities** we saw from this part of the work were:

- AR can be switched on/off on the headset.
- The screens can report what surgeons see and the names and additional text information about anatomy, which might be chaotic to have all on the headset.
- Technology can be essential to make student training faster and more straightforward.
- The helmet emits beams of electrons in the non-visible spectrum, requiring cameras to process the signal for the viewer to see the difference. It would be pointless for the helmet to provide independent light from the binoculars, as this light does not emit in the visible spectrum.
- If a system changes how surgeons operate, it must provide a significant benefit compared to the old method. It is always preferable, however, to design the future object with commonly used interactions.

Lamp Development

Prototyping Lamp

Observing real-time surgeries in a hospital setting provided valuable insights into the optimal placement of a light system for a surgeon's headset. During the observation, it was essential to note the position of the surgeon, the surgical instruments, and the target organ. By carefully observing these elements, we could develop different possibilities for the light system location. No matter what kind of surgery is being done, it is always important to consider the position of the surgeon during the surgery. Typically, the surgeon is positioned behind the patient and is looking down at the surgical site. Therefore, the light system should be located in a way that provides illumination from above and at an angle suitable for the surgeon's perspective. It is also essential to consider the placement of surgical instruments during the surgery. The light system should be positioned so that it does not interfere. In the next step, we focused on constructing the light system and the light system ergonomics.

Design Limits

The primary design limits for the light are size and weight. The size must be small enough to unobtrusively mount on the headset and not interfere with adjustment points. The weight needs to be kept to a minimum since any increase in weight carried by the user's head will increase muscle fatigue. The consortium gave our target weight for the lamp 25 grams to keep the headset as light as possible for added comfort during long surgeries. We also want to maximise the light output. Thus, there is a clear trade-off between the lamp size and maximum power output.

Headset

The purpose of creating a prototype for the surgeon's headset was to understand better its function, design, usability, and comfort. By building a physical model, we could analyse the headset's various components and assess their functionality and how they might be improved. As we already had the dimensions, the final prototype gave us a better understanding of the head size. We also examined the overall look of the headset, considering factors such as its shape and size and how these elements might affect a surgeon's perception of the device. Through this process, we gained valuable insights into the challenges and opportunities of designing the light source. Considering the functionality and surgeons' ease, this prototype helped us develop more ideas on where to put the light source.

We made the headset prototype to have a physical mock-up for a base for further lamp developments and a physical representation of our system for the Half Way Show. We started by examining the photos sent by our Dutch colleagues. We used them to approximate the visor's volume and reproduce its dimensions as accurately as possible. It enabled us to create an object that would help us simulate the surgeons' movements and improve the ergonomics of the lamp.

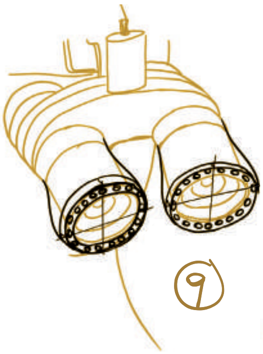
The photographs contained few scalable references, so the dimensioning process was long and tedious. The first information arrived weeks after the request, and our client could not share technical drawings as she claimed they were confidential. In total, it took 20 hours to get all the dimensions. We created mock-ups with cardboard to verify our measurements.

The next step was to create a more accurate model with more particular materials: high-density plastic foam and fibre plastic cylinders. We also considered how the visor's joints interact and how to incorporate them into the model. To determine what would work for us, we conducted several tests with pins, nuts, and pieces of cardboard. It enabled us to model the materials so the joints were barely visible.

Once we created the functional model, it was modelled again in Fusion360's virtual environment and then printed in ABS. This step was critical, as the joint had to be precise, small, and robust. We wouldn't have been able to achieve this with the materials available in the lab in the time frame we had, as the Half Way Show was a week away. It took 40 hours to get the helmet completed.

As the physical model of the visor was made and painted, we assembled it with a welding mask headband to complete the headset. The result (see Figure 10) resembles well headsets that the end-users work with. The quality of the prototype was good and fulfilled its purpose. We consciously excluded the features such as weight distribution at this phase. The Master's thesis that was defined based on this project, however, will focus on these features in more detail.

Figure 10: The first prototype of the headset.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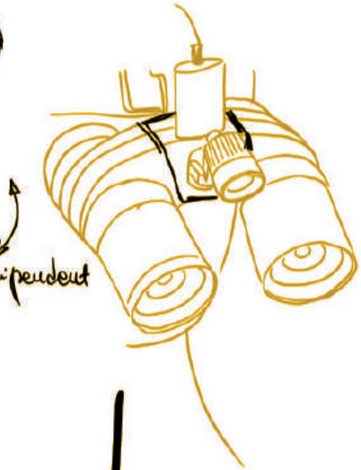
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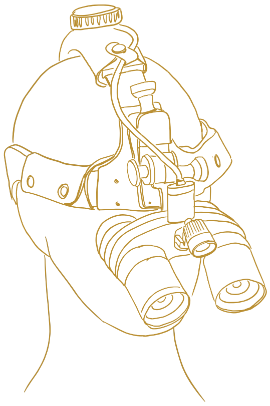
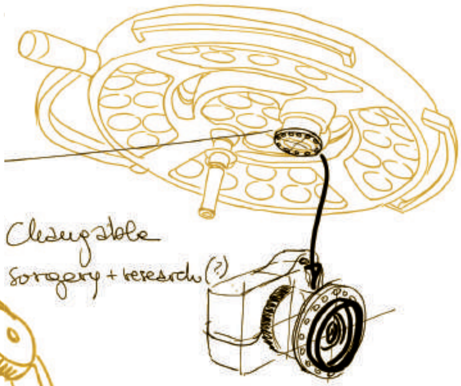
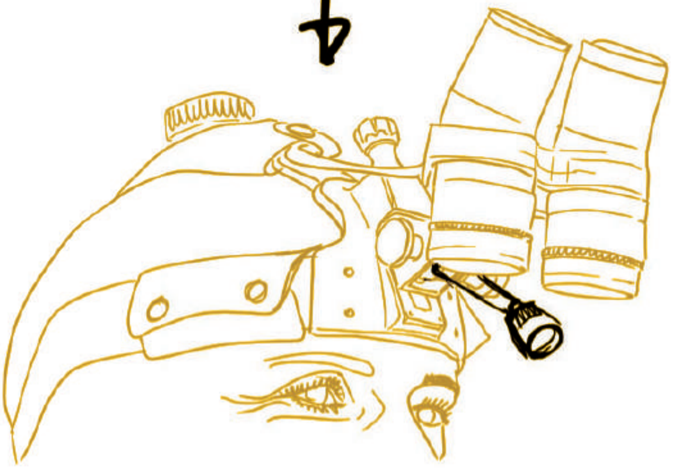
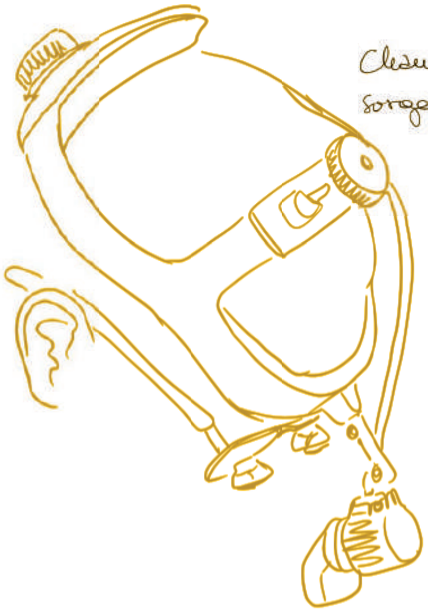
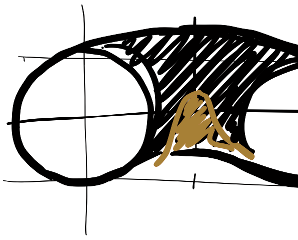
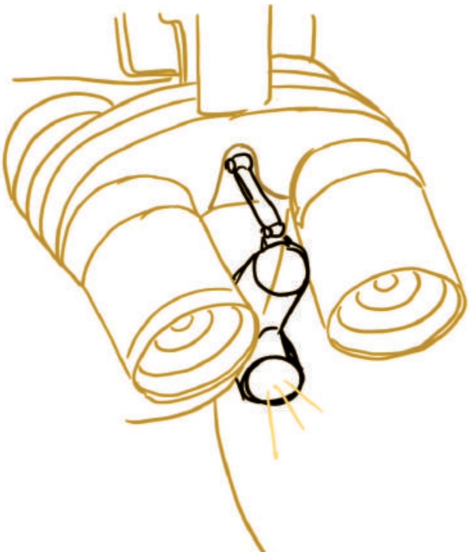


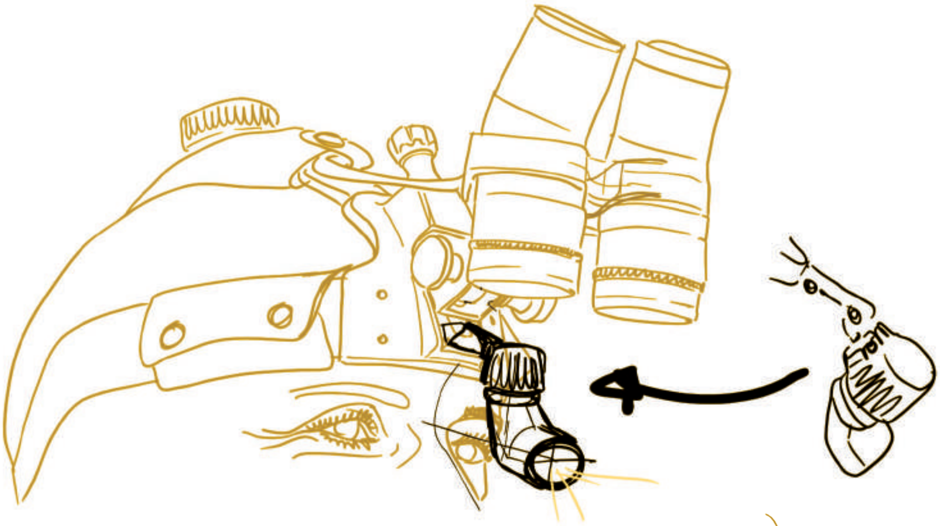

Changeable
surgery + research (?)

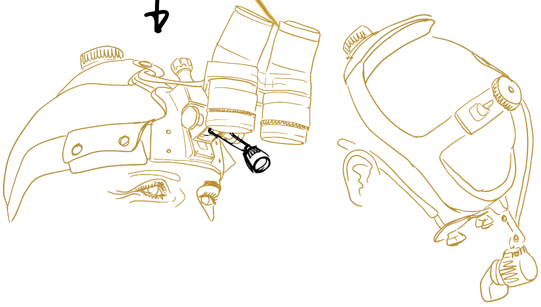








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Lamp Concepts

Many concepts were proposed for the light and shape. We determined that there was a real risk that a small head-mounted lamp would not be powerful enough to be helpful for the hyper-spectral camera. With this in mind, some alternatives where the light would mount on a traditional operating room light were considered. However, since our goal was to create a surgical NIR headlight, these ideas were left more as a backup plan as we moved on to ideating different lighting configurations for the headset.

Many concept ideas focused on putting the maximum amount of LEDs on the headset to gain full illumination power. However, due to the high prices and long lead times of the NIR LEDs, we decided to focus on a smaller lamp size. If we were to do an ample panel light for maximum illumination, we would not have any LEDs left as a backup should something go wrong. Smaller lights will also make the integration into the headset easier, and we can build three or four different prototype lights before we run out of LEDs.

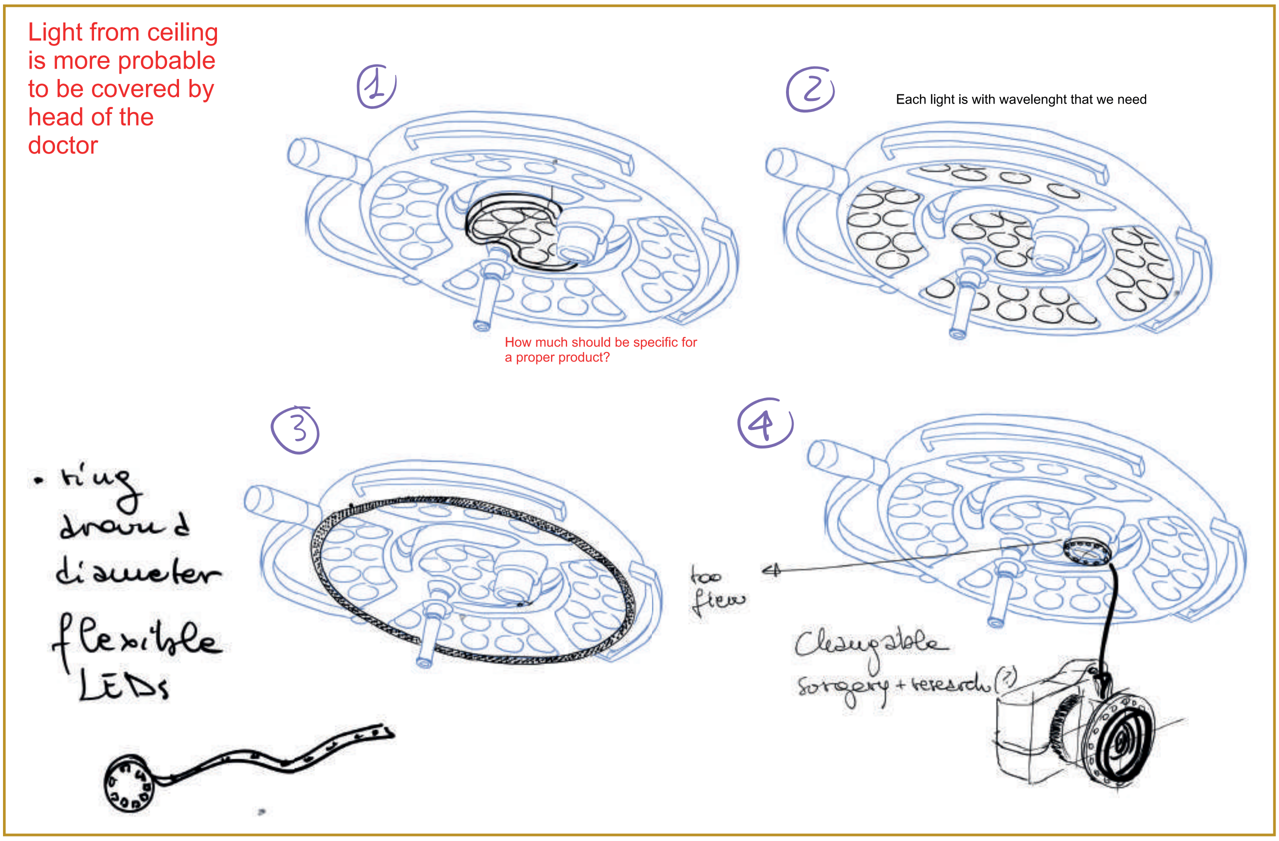


Figure 11: Sketch of the ceiling lamp in the Operating Room.

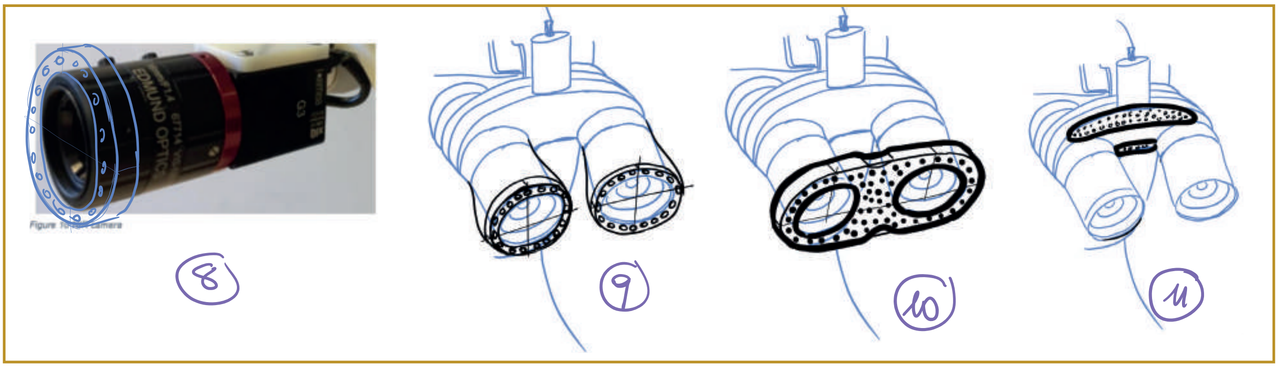


Figure 12: Sketch of possible locations for the light.

The other characteristics we considered necessary in creating and choosing the best concepts were: being flexible and adaptable to different angles, being able to fit a large number of LEDs (>7), moving the centre of gravity of the overall object outwards as little as possible, finally, the prototyping feasibility (by this, we mean if we already knew that the thing would not work or we would not be able to produce it at prototype level with the skills present in the team or within the Design Factory).

With this in mind, we devised four distinct concepts for the light.

1. The **"Over"** lamp is the advanced light option already on the model now in use by the manufacturer. Then a conical lamp is positioned between the two cameras. Our modification was to lengthen the cone to the end of the two cameras to avoid the presence of shadows. Fundamental is the joint design that connects the lamp to the binoculars. A critical point is the possible need for a lens for better light distribution.

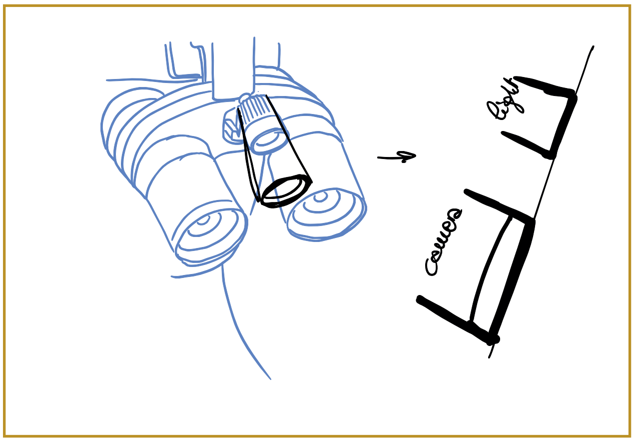


Figure 13: Traditional light that mounts above the two eyepieces.

2. The **"Under"** lamp resembles the "Over" lamp. The only difference is the position of the object. If the "Over" is mounted above the binoculars cameras, the "Under" is mounted below the cameras. The excellent point about this change is that it moves the headset's centre of gravity inward, not outward.

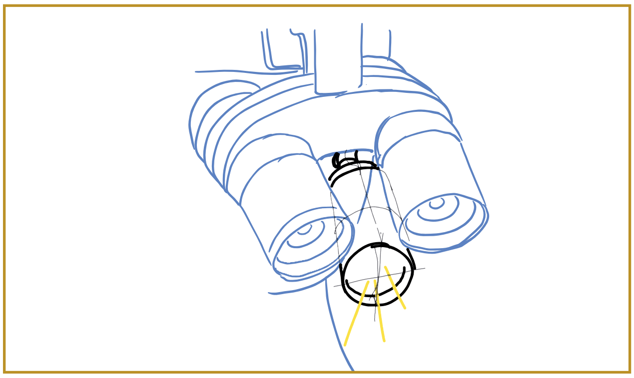


Figure 14: Light that mounts under the two eyepieces

3. The **“Offset”** design was proposed as a possible solution in earlier phases. This shape derives from the prototype we saw from the work of a Dutch colleague who had created a similar ring-shaped lamp that he placed around an IR camera. Our modification was inserting two rings around each camera in the binoculars. Another positive point was that it could hold many more LEDs than the “Under” or the “Over”.

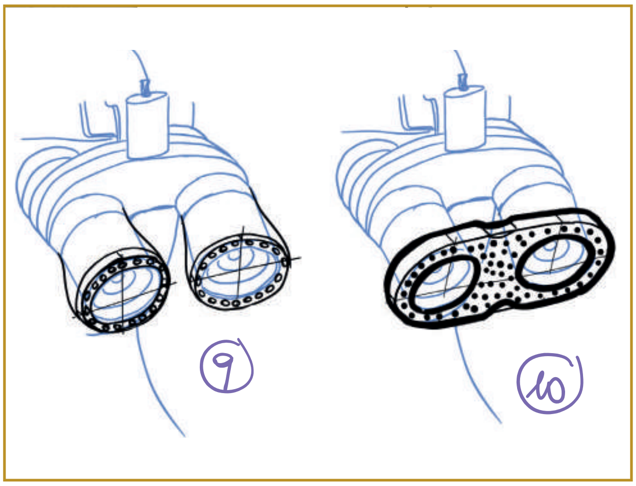


Figure 15: Light rings supported on the two eyepieces.

4. The **“Fish Lamp”** comes from visualising the fish with the bait on its head as fluorescence. The positive features of the shape are that it does not depend on the viewer’s side but starts from the centre of the helmet. It limits the displacement of the object’s centre of gravity, and the light is independent of the binoculars’ chambers. Finally, making the artefact with a flexible body was essential so the user could independently adjust the light’s direction.

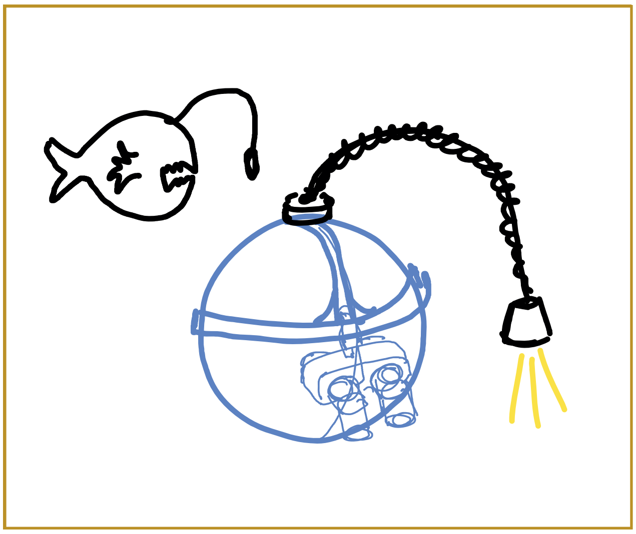


Figure 16: Separate adjustable arc light that mounts onto the headband instead of the headset.

Lamp Development

For this first evaluation we did not consider the details necessary to contain and manage electrical cables for connecting the PCB to an energy source. We decided to model the lamps’ shape individually and make static plastic joints to connect the light to the main body to simplify the modelling. These joints do not allow any lamp rotation, making all models easier to evaluate. We agreed that once the best candidate was found, we would consider the best type of joint to facilitate lamp rotation if this feature was deemed necessary. A note on the technical drawings: these were made according to UNI-ISO standards, with European projection and units of measurement in millimetres.

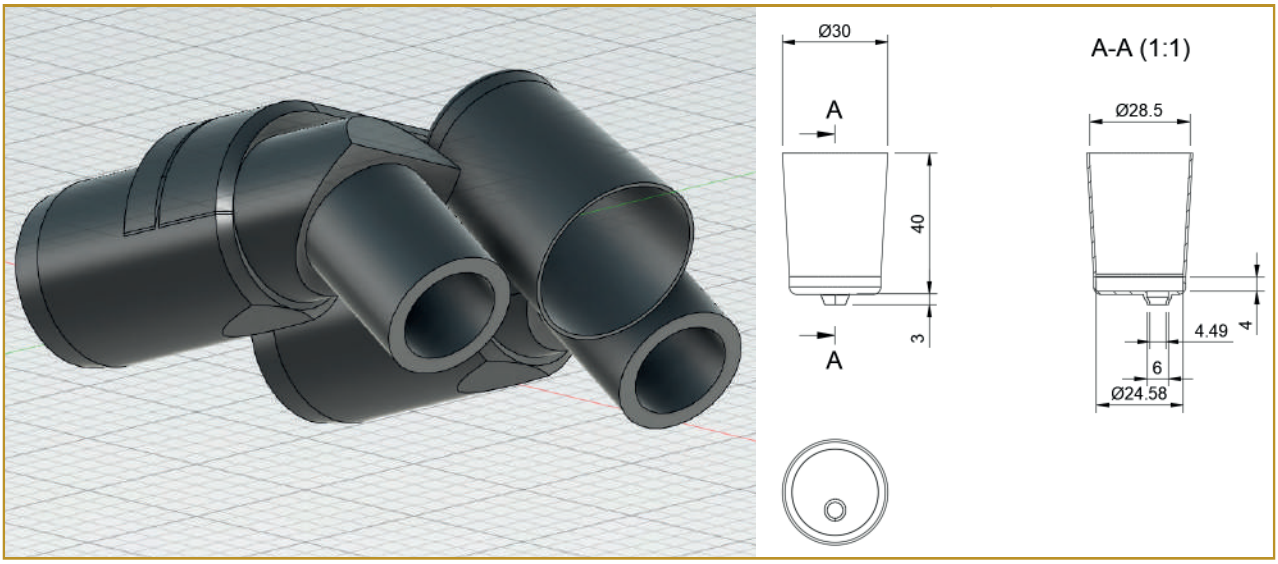


Figure 17: Traditional light that mounts above the two eyepieces.

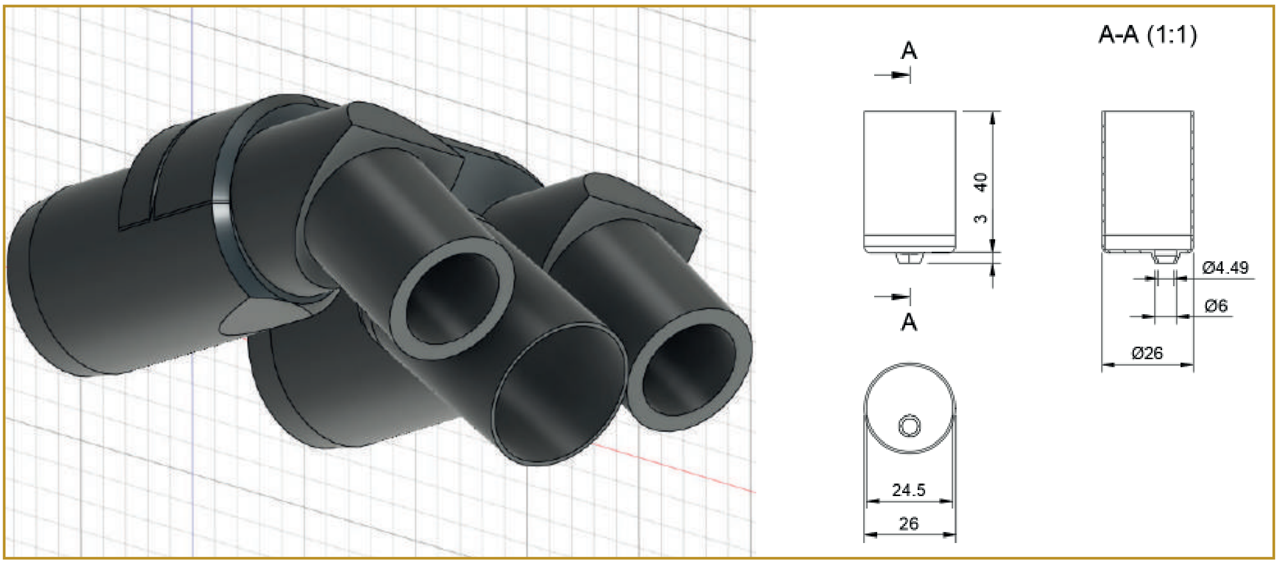


Figure 18: "Under" light that mounts under the two eyepieces.

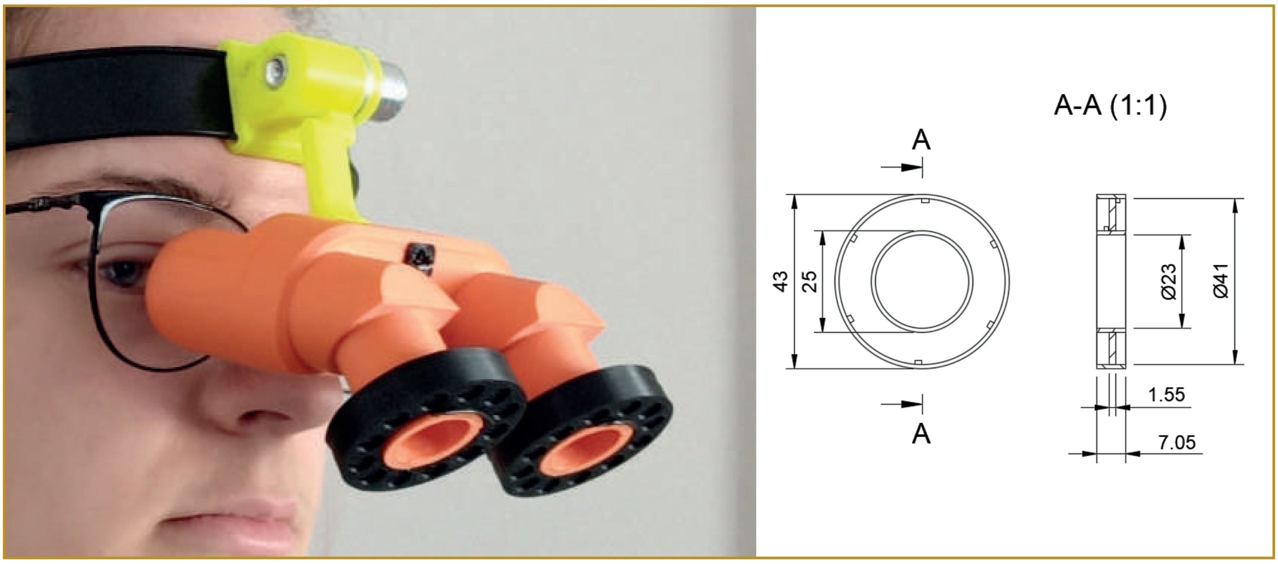


Figure 19: Light "Rings" that mount onto the two eyepieces.

The modelling of the fourth concept consists of a rigid arch that rotates from a joint above the ear. The light can have two positions: one faces in the same direction as the cameras, and one directs upwards when not in use or only the binocular part is to be operated.

While modelling the fourth option, we realised we could create something more flexible, so we made a model with copper wire and added the lamp to one end. The body of the wire passes between two metal washers fixed to the top of the helmet so that the cable can slide and bend to remain flexible and less bulky than the first idea.

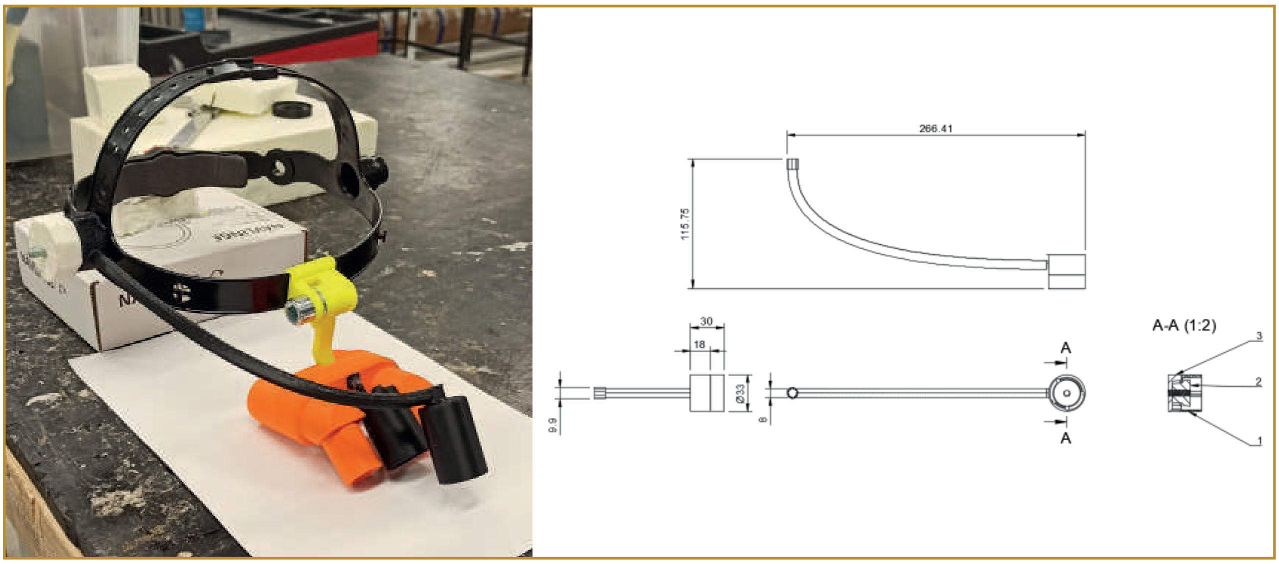


Figure 20: Separate adjustable arc light that mounts onto the headband instead of the headset

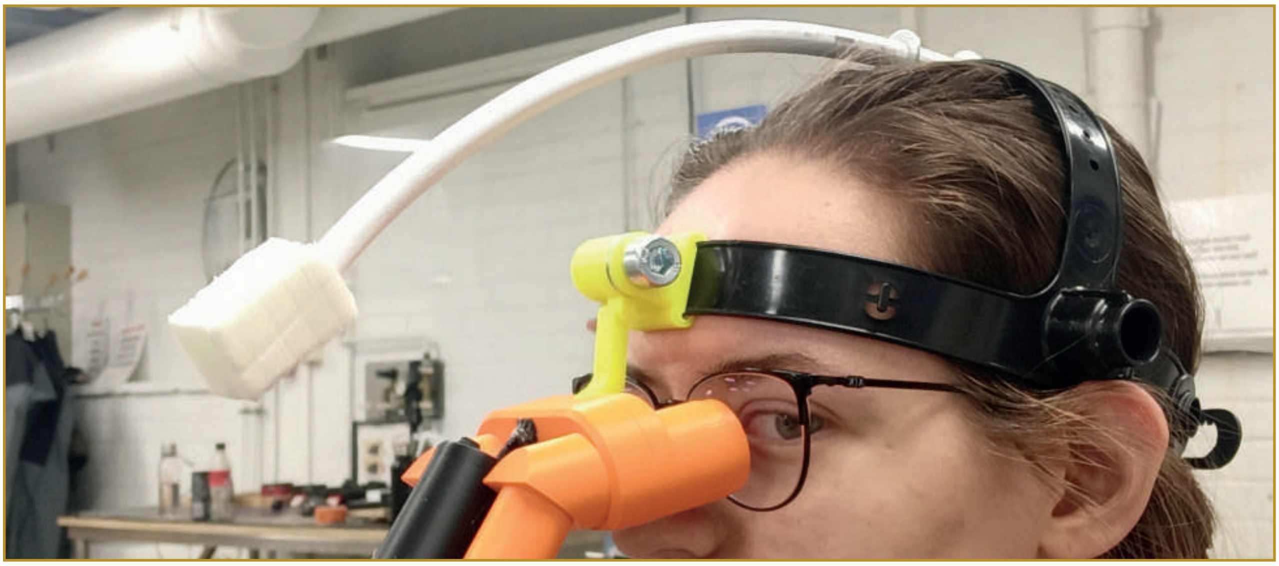


Figure 21: Flexible cable light mounts onto the headband instead of the headset.

Ergonomic Test

After brainstorming, five different models were proposed. The models were similar in terms of using the same headset and the same eye part; however, the location of the lamp and the maximum number of LEDs that could be used for each model were different. A test chart (see Appendix 4) was developed to assess each model's various features and make a comparison. In the test chart, both the ergonomics and the light aspects were mentioned; however, we only focused on the ergonomics in this section. Different factors related to user feasibility, weight and dimensions were analysed. To complete the table five people tested the models, but only some people tested all five. While testing each model, they were asked to answer some questions, and their answers were used to fill in the table. The questions (see Appendix 5) were developed to cover the details related to the system ergonomics since the involved people were not surgeons. For the results, they needed to perform similar activities as surgeons during surgery.

The testing outcomes showed how different models are from each other and the advantages and disadvantages of each system. Finally, the angler fish model showed more promising results than other models. At this stage, we did not omit any model, and the primary goal of this assessment was to compare the different features of the proposed models.

Model	**Positive Feature**	**Negative Feature**
Upper	Small volume, less space.	Light angle and light part length hard to adjust.
Downer	Small volume, less space.	Light angle and light part length hard to adjust. Lamp case is in contact with the user's nose.
Rings	High number of LEDs can be inserted if needed.	Light angle and light part length cannot be adjusted. Not possible to add lenses if needed.
Right Arc	Light angle can be adjusted. Highly resistant structure. Lamp case adjustable.	The structure add weight to the overall headset system.
Angler Fish	Light angle and lamp case length can be adjusted.	The structure can't stand the light system weight.

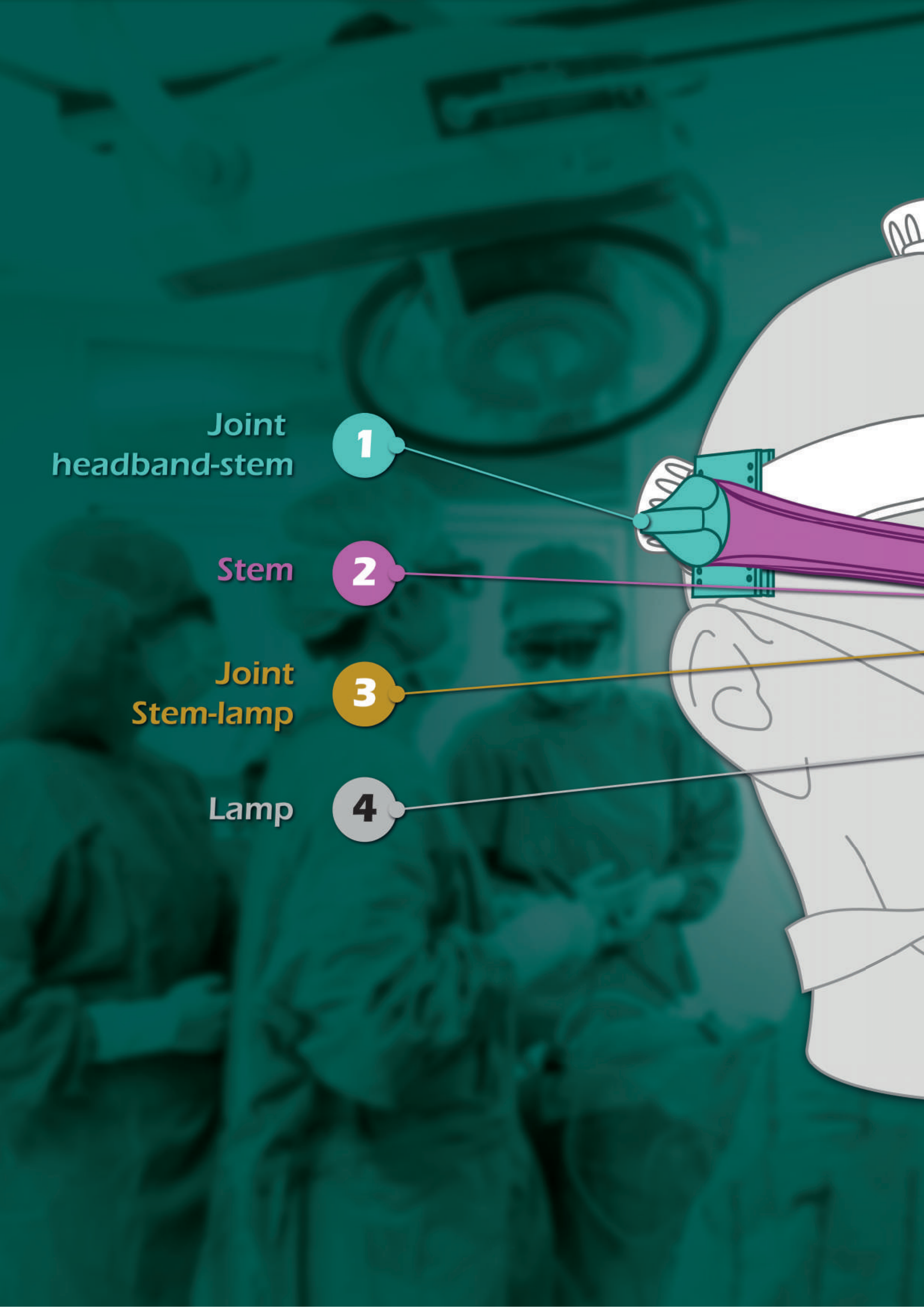
Decision

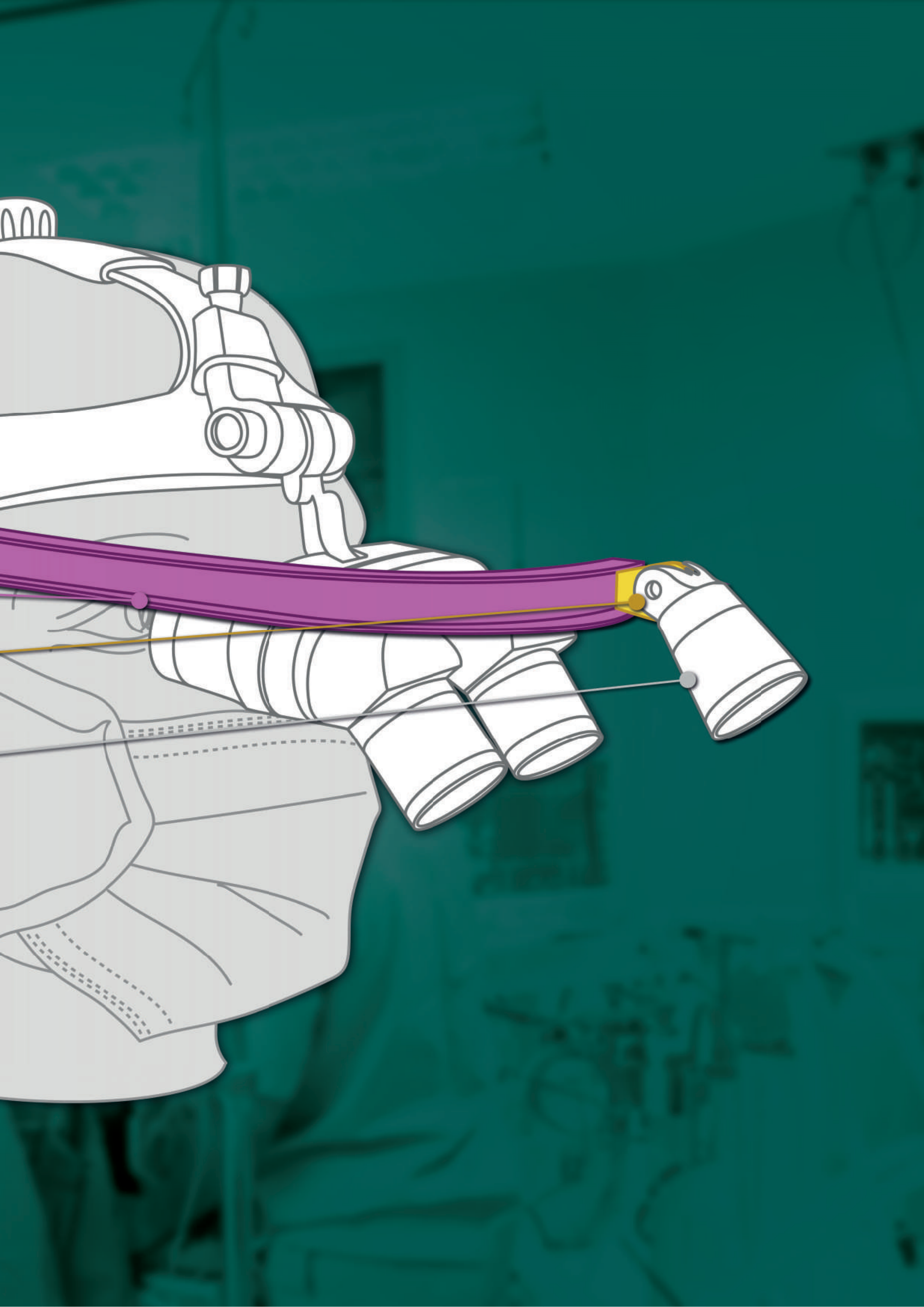
Ultimately, it was decided to proceed with the Right Arc design. The reasoning was that the light angle and location could be easily adjusted. It does not interfere with anything and can withstand our light system weight.
The under-mounted lamp was discarded because it impeded the user's nose. The two-ring design was not wrong in and of itself, but we decided that we wanted to have the possibility of adding a lens in front of the LEDs in case we needed to focus the light more. The ring design doesn't allow for this and therefore was discarded from consideration.

Final Model

After deciding what type of prototype to develop further, there were final touches to the model. These changes were necessary to optimise the shapes to withstand at least 500 grammes of weight, flex as little as possible, and be manufacturable by 3D printing.

The joint to attach the model to the headband was redesigned to be universal for each headband so that it can also be used directly with the product our customers are developing. The cross-section of the central stem has been changed from circular to an I-beam to be more resistant and have more organised access to the cables connecting the light to the energy power. The joint connecting the stem with the lamp was designed to respect the dimensions of Go Pro products, as was the PCB housing. In this way, if the light is used in locations other than initially intended, it will be easy to adapt the connecting stem with a Go Pro product, which remains reliable and inexpensive. The final model was printed in Nylon, and it weights 30 grams. To see the technical drawings have a look to Appendix 6.


Joint headband-stem
1
Stem
2
Joint Stem-lamp
3
Lamp
4



Electronic Development

First proof of concept electronics prototype

We wanted to build a very simple testing rig to take with us to the spectrometry laboratory. The goal of this prototype was to test our vision of tuning the LEDs and what kind of properties and wavelengths we need for the actual prototype. Our goal was to get as flat and unified a spectrum through 700-1000 nm as possible. We first built a circuit to the breadboard with visible light LEDs to confirm that we can use trimmers (small potentiometers) to control the intensity of the lights. Through testing, we ended up using 1k ohm trimmers that gave us the greatest control. We also noted that PWM signals from the microcontroller can be used to control the intensity, which means that the camera itself can also adjust the lighting if needed.

After proving our concept with visible light, we switched to NIR LEDs we had ordered for the first testing. They are far away from the power of the LEDs we were planning to use, but are suitable for testing. In the schematic below, you can see the electronic configuration we ended up with. We chose to use 9v batteries as the power source since it makes it easy to go and test the solution in the laboratory.

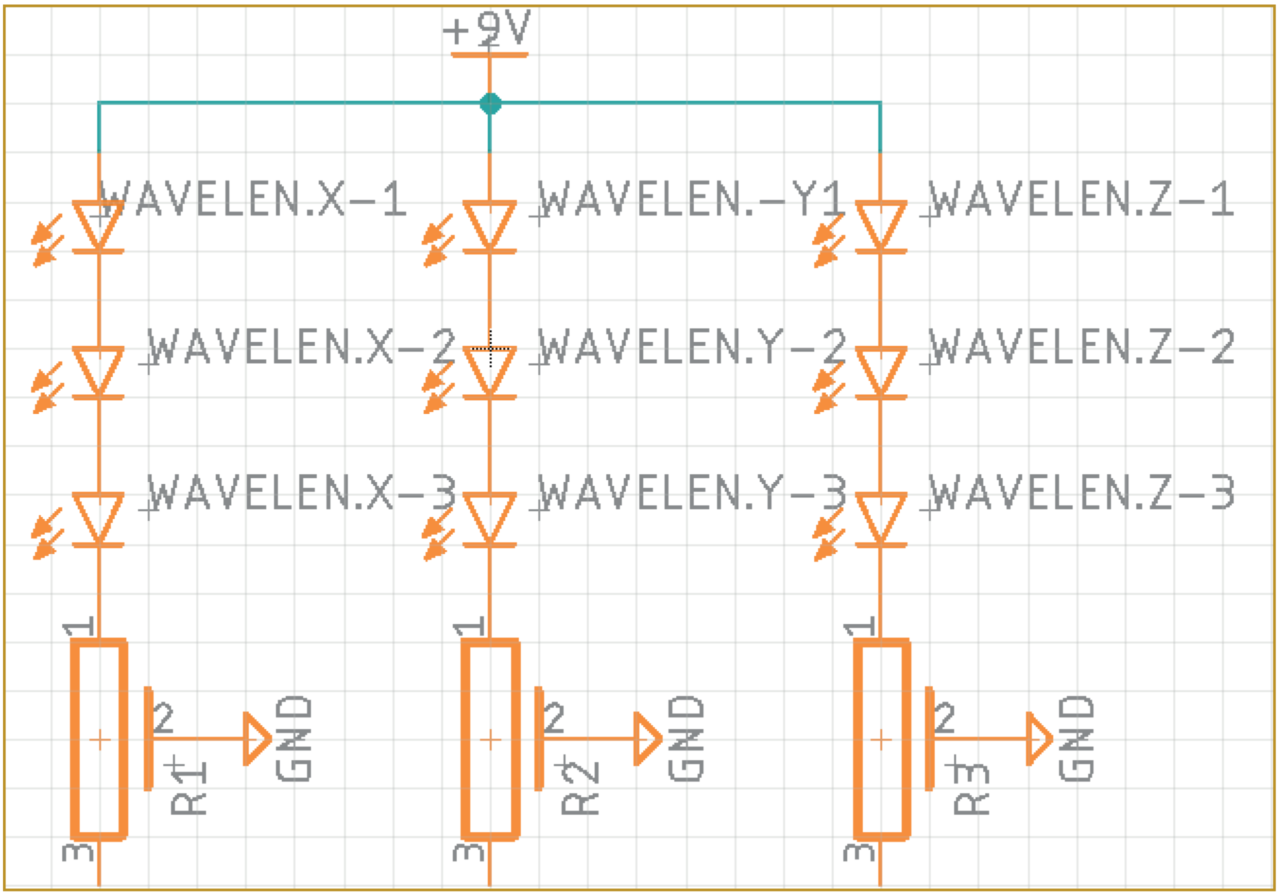


Figure 22: Different wavelengths are parallel, and the same wavelengths are in series. With the trimmer, we can control voltages through each wavelength.

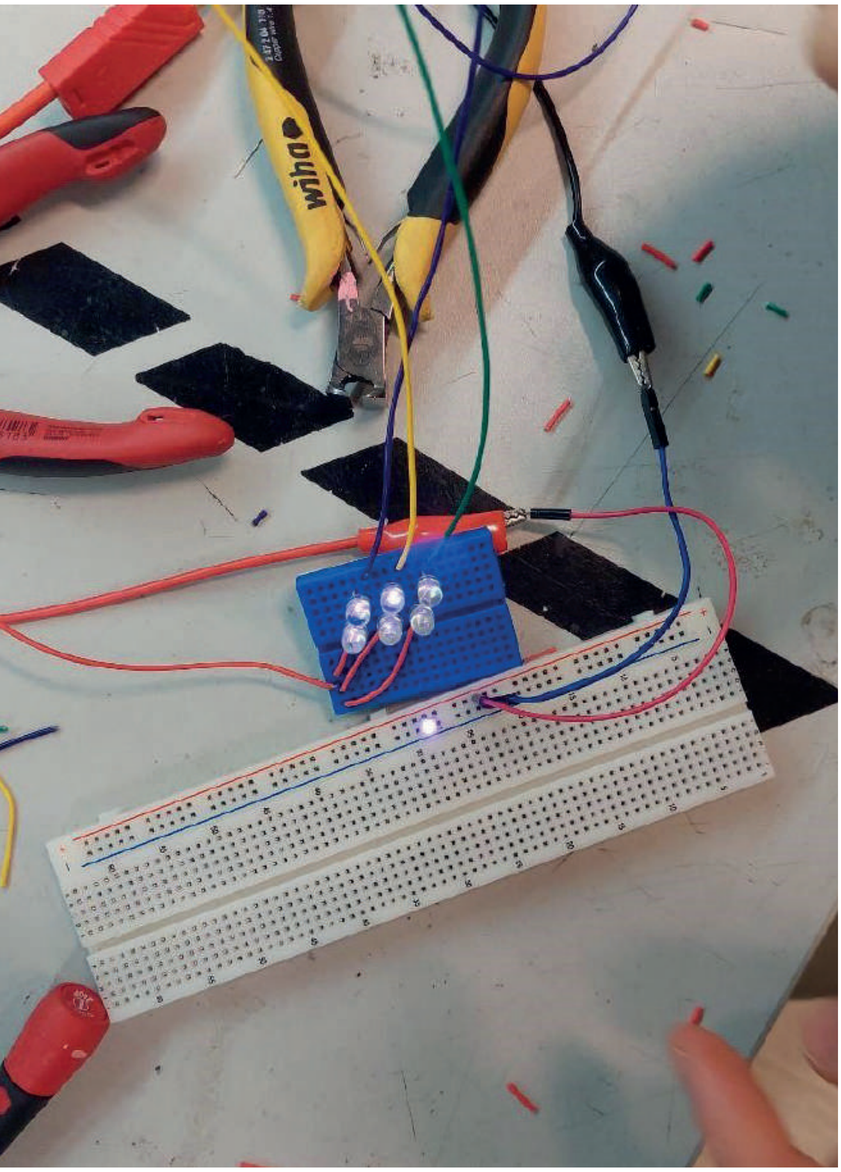


Figure 23: Configuration of LEDs

We split the power circuit from the LEDs to make testing more manageable in the laboratory. Figure 23 below demonstrates the configuration and functionality of the system. You cannot see if the LEDs are "on" by the naked eye, but you can still see them with a phone camera.

First test bench and PCB

We built a testing bench and PCB showed in Figure 24 below to measure the NIR LEDs we got from Ushio. Ultimately, we did not end up using the test bench but instead, just put the spectrometer on top of the individual LEDs by hand. For this prototype and the coming ones, we used a Bantam tools desktop mill as a PCB mill for this prototype and future ones to make our own custom PCB at the Aalto Design Factory.

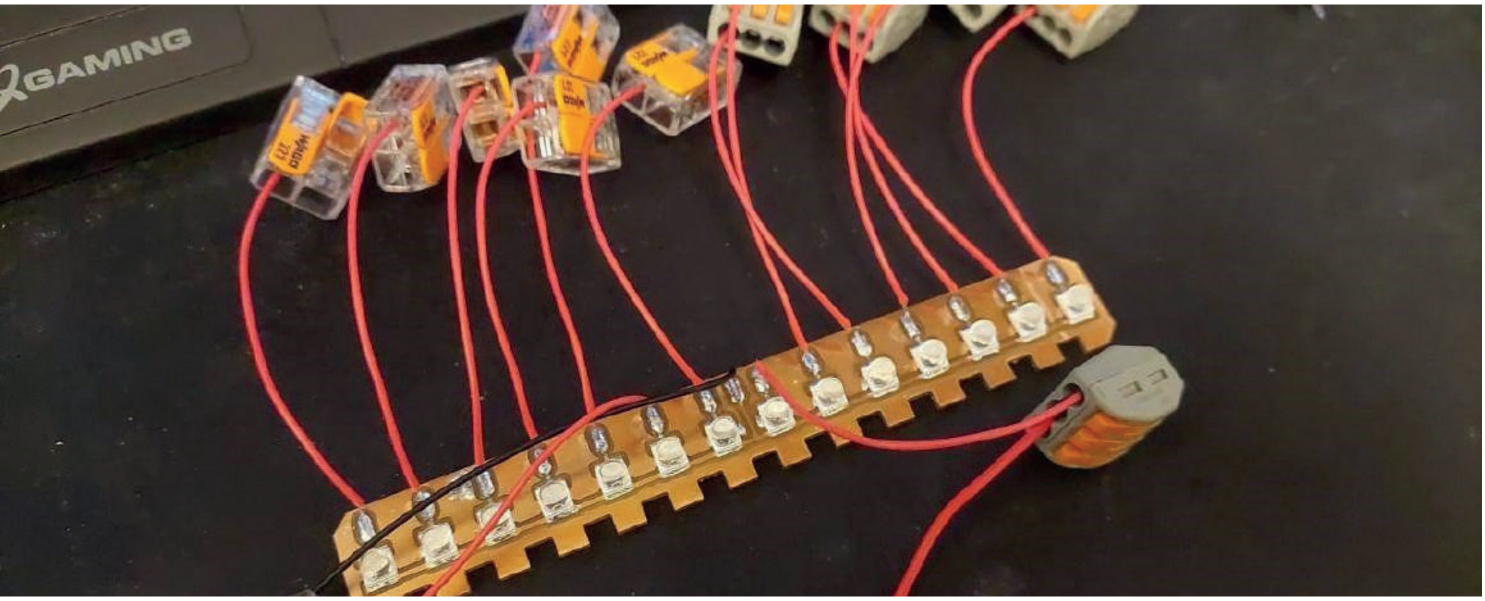


Figure 24: Custom PCB

This test produced the graph in Figure 25, representing the intensity responses from each specific wavelength. We used this as a reference for the actual tuning. This test was done with a led driver board that delivered constant 1A current through the LEDs during measurements.

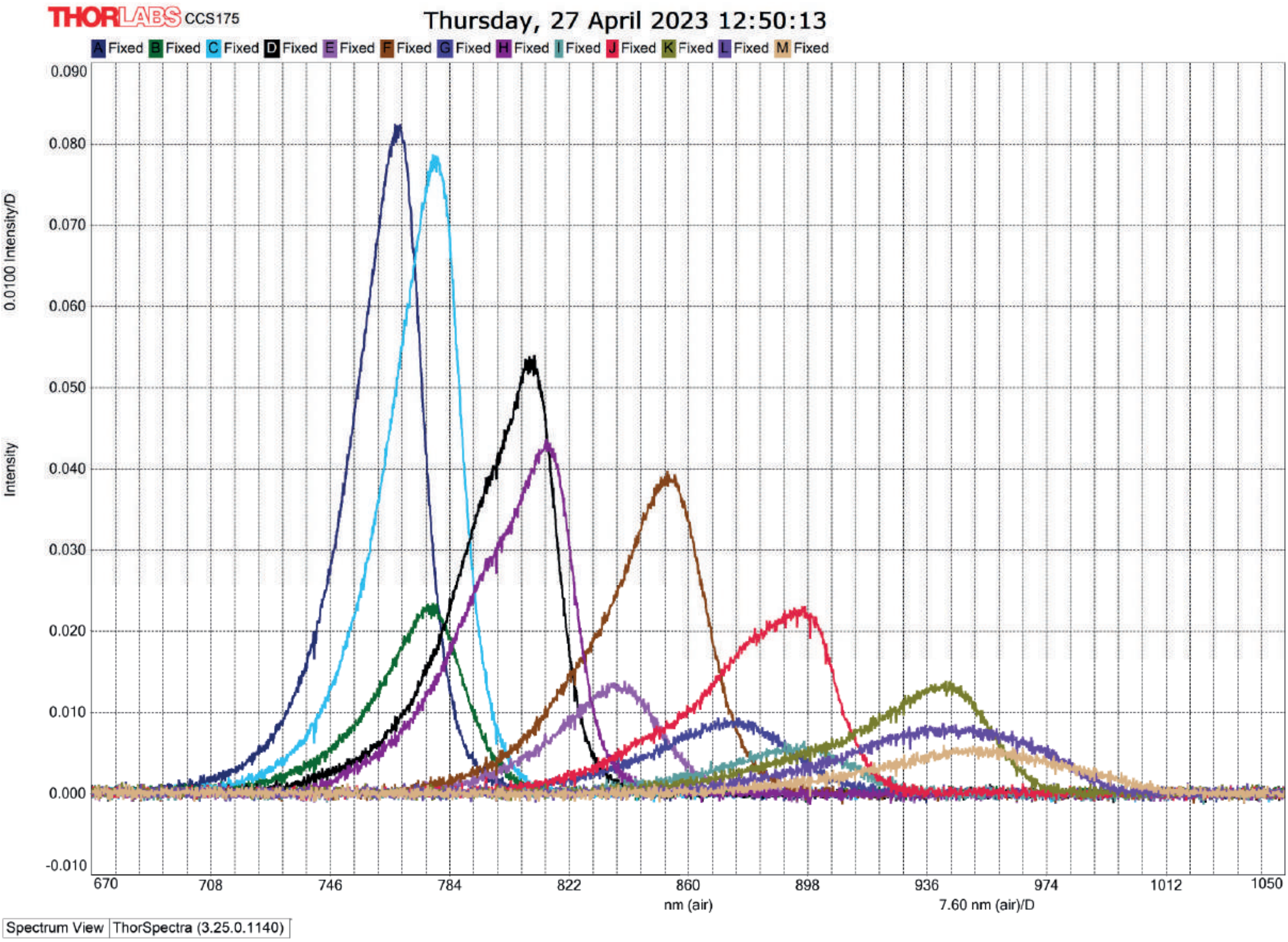


Figure 25: Representation of the intensity responses from each specific wavelength

Tuning

We built a new test bench for the tuning. We needed this to measure the combined spectrum of different wavelengths since they overlap and multiply each other. The test bench was modelled to fit custom pcb:s, where we could mount our SMD LEDs and print in the Df from PLA. The test bench and custom pcb's can be seen in Figure 26.

We used only three led drivers in the first tuning tests, each providing a steady 1A current. The drivers were driven by their PWM signals from Arduino Mega so that we could dim them individually. The test produced the outcome seen in Figure 27. We added ten drivers for a total of 13 to control every wavelength individually. This development challenged the power source since we needed around 14A current and a minimum 6V voltage. The tuning setup is presented in Figure 28.

Figure 26: The test bench and custom pcb:s

With the tuning done, we ended up with a flat and sustainable curve that is easy to implement and modified by the camera's input. The biggest downside is that the driver tower, shown in Figure 29, is quite substantial (around 5 x 5 x 20 cm), but it can be mounted to a waist or a table, for example, and it is easy to shrink down with integrated circuits.

The final spectrum is shown in Figure 30 below. For the final prototype, we added LEDs to compensate for the drop that can be seen around 830nm and 880nm. The changes look drastic, but the difference is actually around 0.02, so relatively small. Unfortunately, we didn't have enough LEDs to test them in tuning. When viewed on a bigger scale, it is easier to understand how small the changes are.

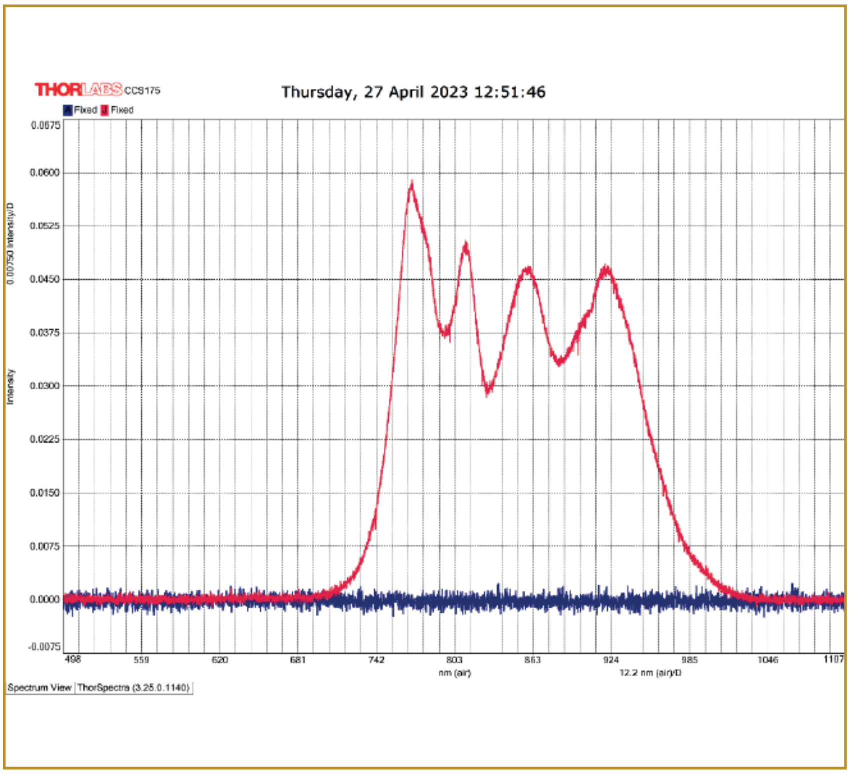


Figure 27: Results of the first round of tuning with three LED drivers

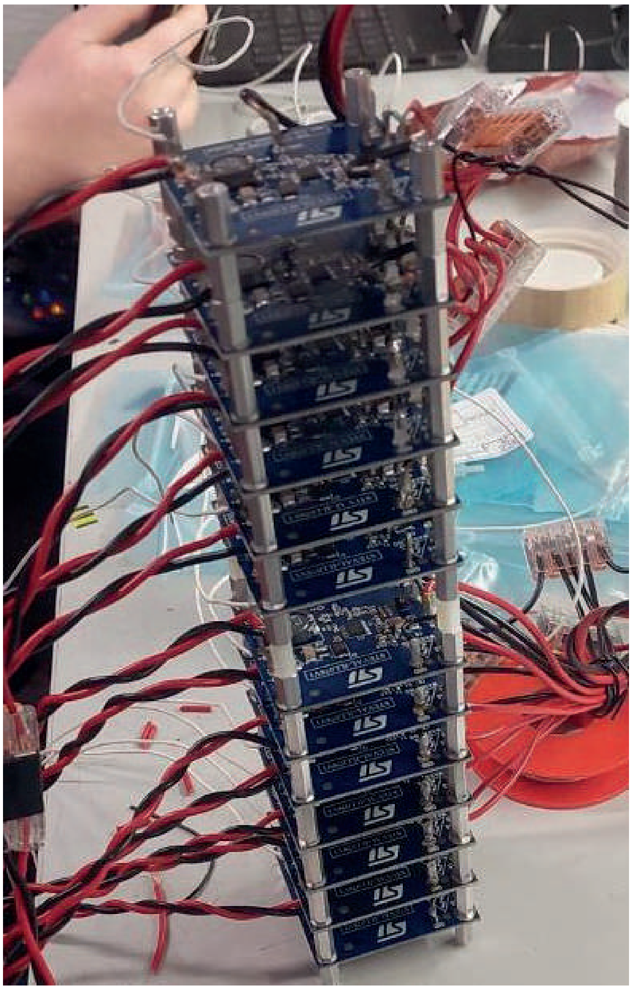


Figure 29: Led driver tower with 13 drivers.

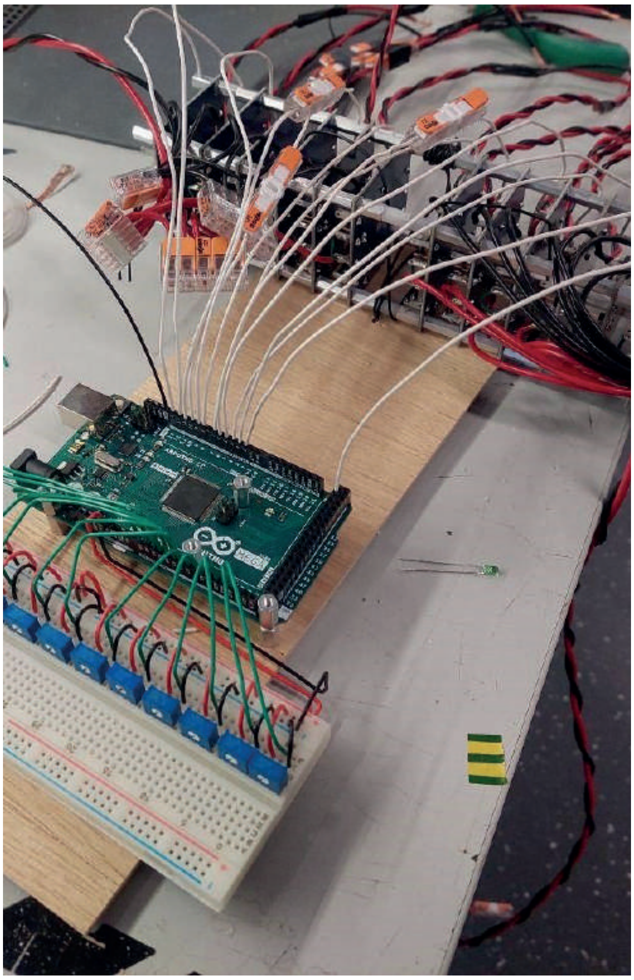


Figure 28: The tuning setup with Arduino Mega, potentiometers, and LED drivers.

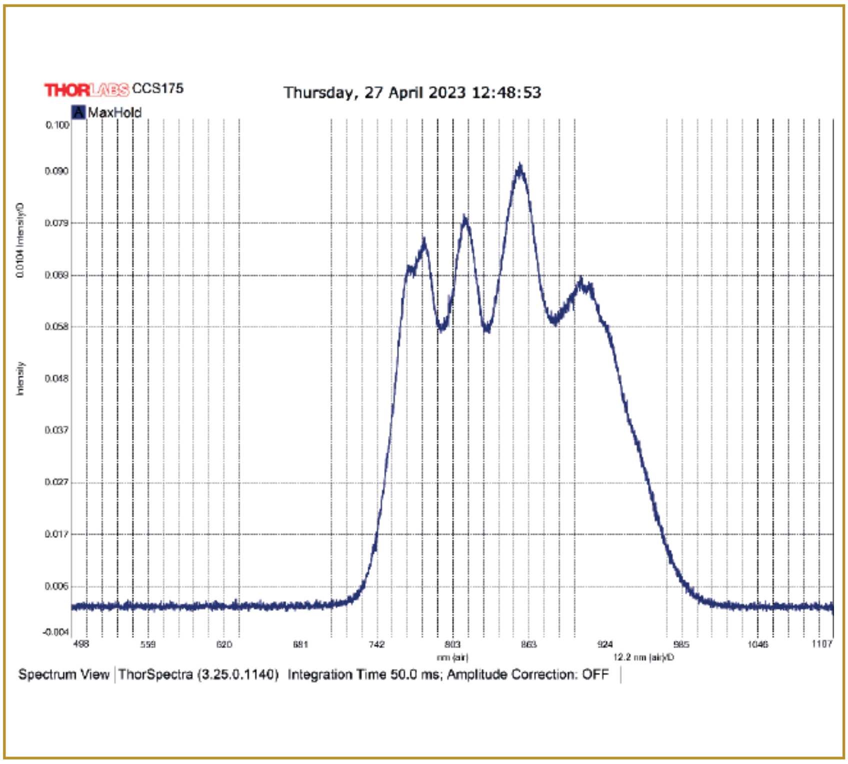


Figure 30: Final Spectrum

Power Pack

While the working prototype was forming, the need for a power source was more relevant/topical. The first estimations for the technical details of the power source were 3 to 6 A and 16-32 V. The first research was broad, but it was quickly noticed that such power sources were rare. The first options were laptop power packs with the output voltages and currents in the range. We had a few potential power packs, but those had a shorter delivery time, so we did not choose those, but also later, the technical requirements were updated as the tuning progressed. The second estimation rose amperes to 9 A, which created even more challenges to finding a suitable power pack. Small jump starters became the best options at this point, but we still needed more.

A research mindset became more apparent as the light prototype and power source research proceeded. As we realised that we do not target the final power pack (small, efficient, and light), we decided to distribute requirements to many power packs. This, and calculations of the absolute minimum required details, made selecting the power pack much more straightforward. We only needed voltages 9 V or above and 18 A. This can be achieved by connecting two 9 V power sources with a 10 A parallel.

After finding an easily purchasable power-pack that fulfilled all requirements, we still considered different options. As the running time was one considered property during the whole research process, which could have been better than the previously mentioned option, we continued to look for another option. After a while, we found Li-Po batteries that have enough voltages (as the required voltages decreased again along the progress of the LEDs), and also, its output currency is enough for the lamp.

The final power pack is TATTU 22000mAh Li-Po battery package, with 14.8V. It has good capacity and can be used without modifications (the single pack is enough). This battery is used for drones and radio controlled-cars. As the Li-Po batteries are susceptible to mistreatment, such as negligent charging, our selected battery needs careful charging, storing (never fully charged, storage voltage should be around 3.8V), and maintenance. Li-Po batteries should never be overcharged or let the voltage drop too much. It requires to be stored in a fireproof bag. However, generally, Li-Po batteries are safe to use.

Final Prototype

For the final prototype, we doubled the number of LEDs. More LEDs were used because we wanted to make the light more powerful (see Appendix 7). This fact and the reality that we needed more LEDs than anticipated in the beginning led us to a situation where the light wasn't suitable for mounting in the head. Because of this, we made a GoPro accessories-compatible mount for the case so it can be easily mounted to anything with readily available parts.

The whole holder ended up being 7.5x7.5 cm while the PCB was 6x6 cm. The assembly weighs just under 200g. The prototype is battery-powered, and with 22000mAh Li-Po, it can run for approximately 2 hours. The prototype draws around 12V and 14 A. Overall 30 high-power smd LEDs are used in the prototype. Light assembly is shown in Figure 31 and 35 below.

Since the prototype uses 168W, it is important to heatsink the PCB to the case, and remember that it can get hot. Schematic illustrations of the PCB are shown below in Figures 32 and 33.

To control this, we used the same Arduino mega 2560 and 13 LED drivers as in the testing. They were wired further away and powered by the Li-Po battery discussed earlier. All this resulted in a spectrum shown in Figure 34.

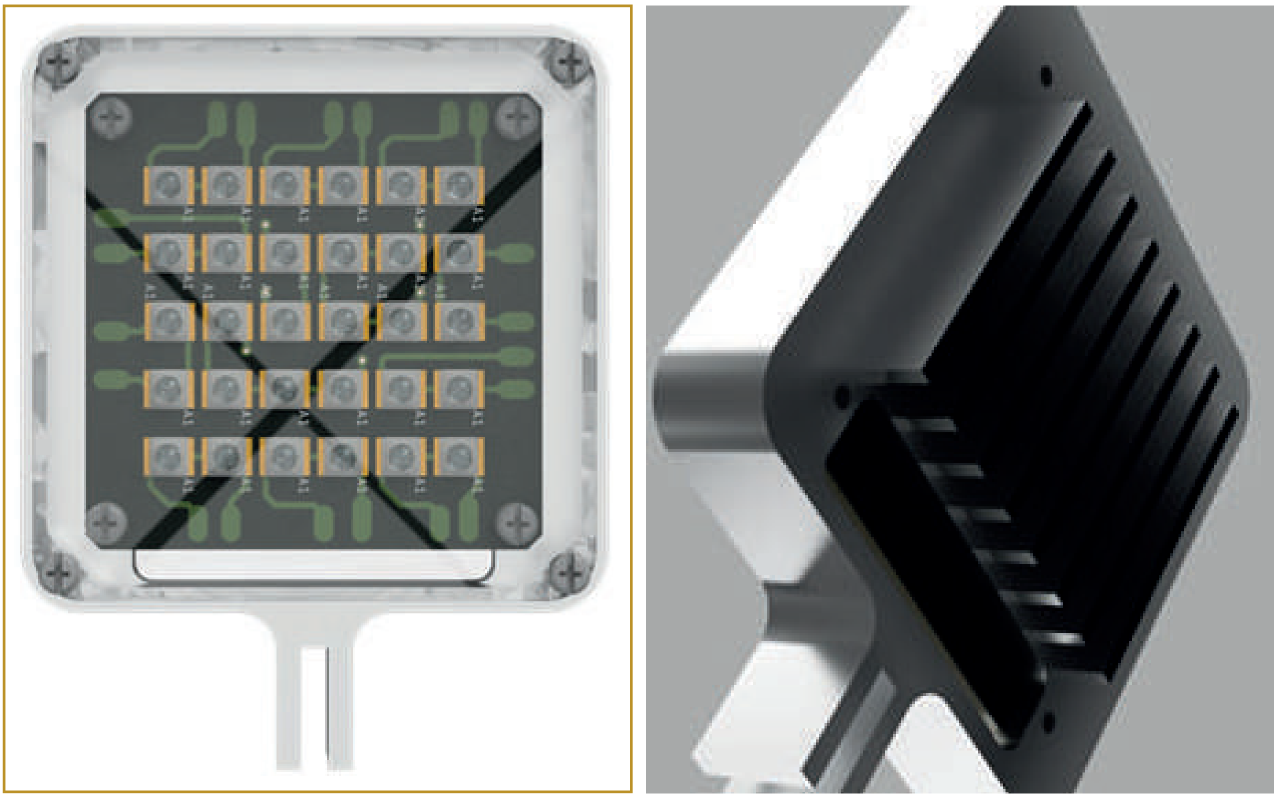


Figure 31: The light case assembly

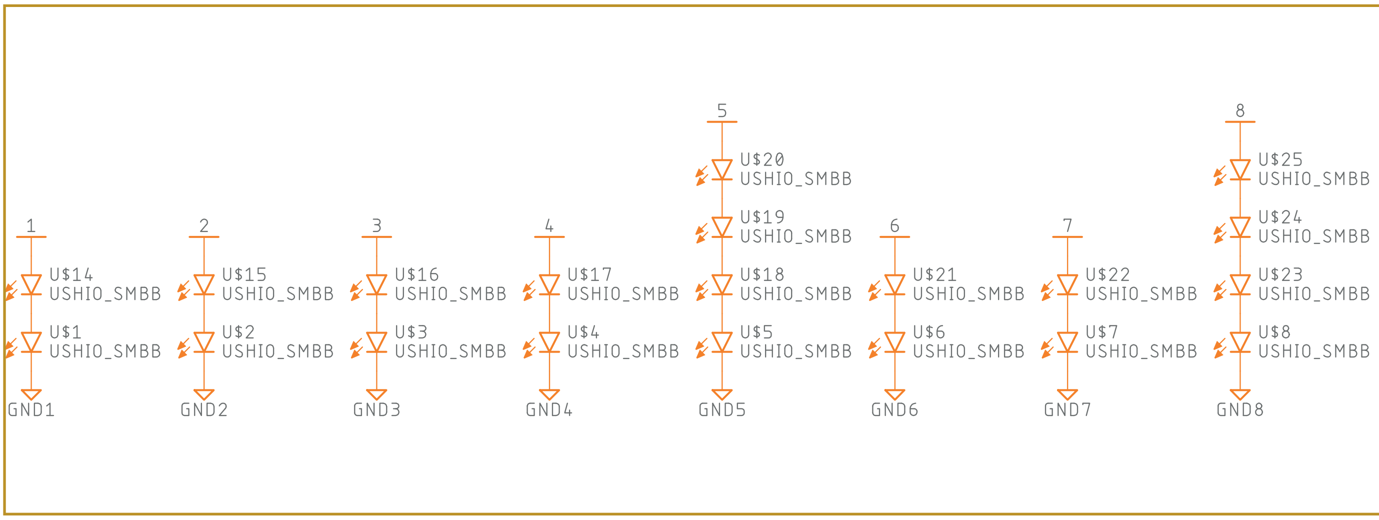


Figure 32: Electrical schematics of final prototype

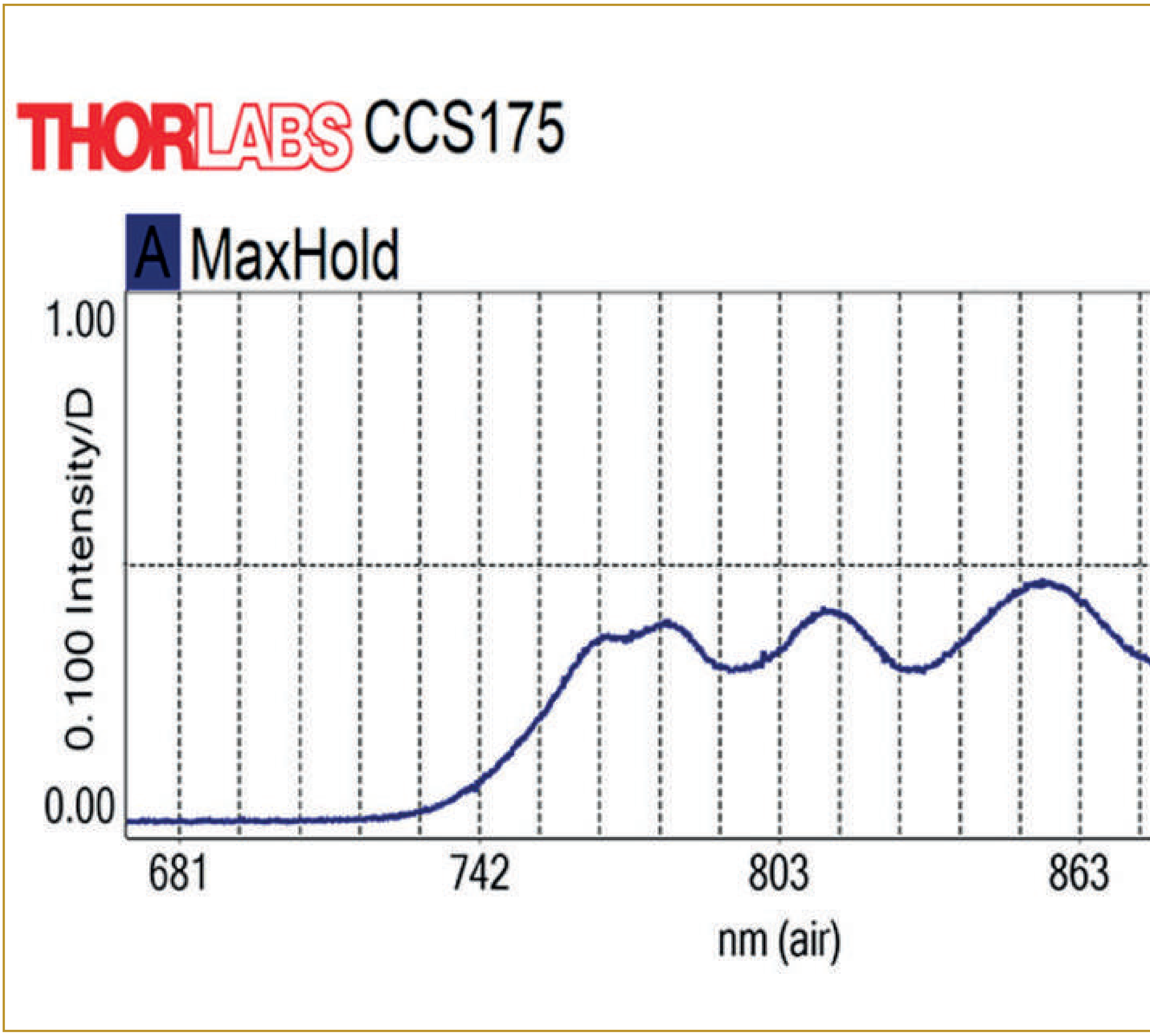
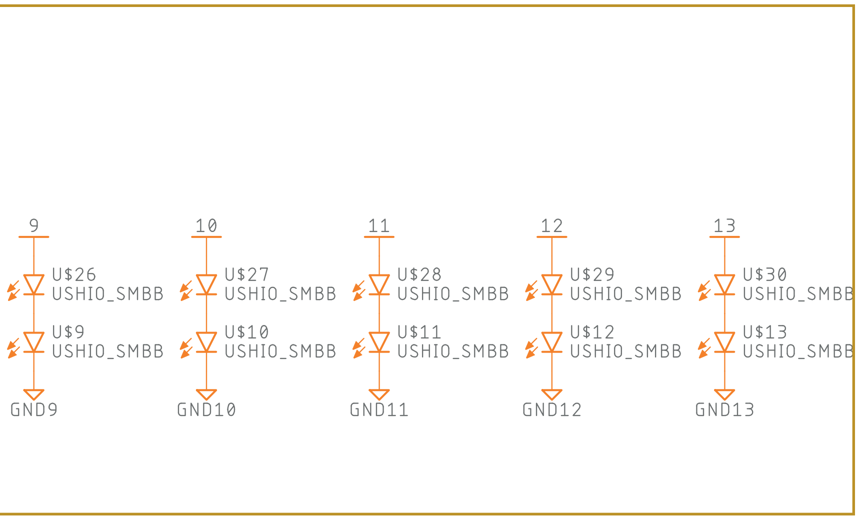


Figure 34: Final spectrum



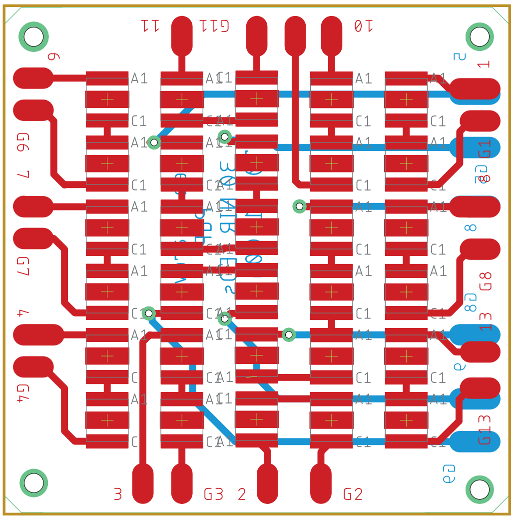
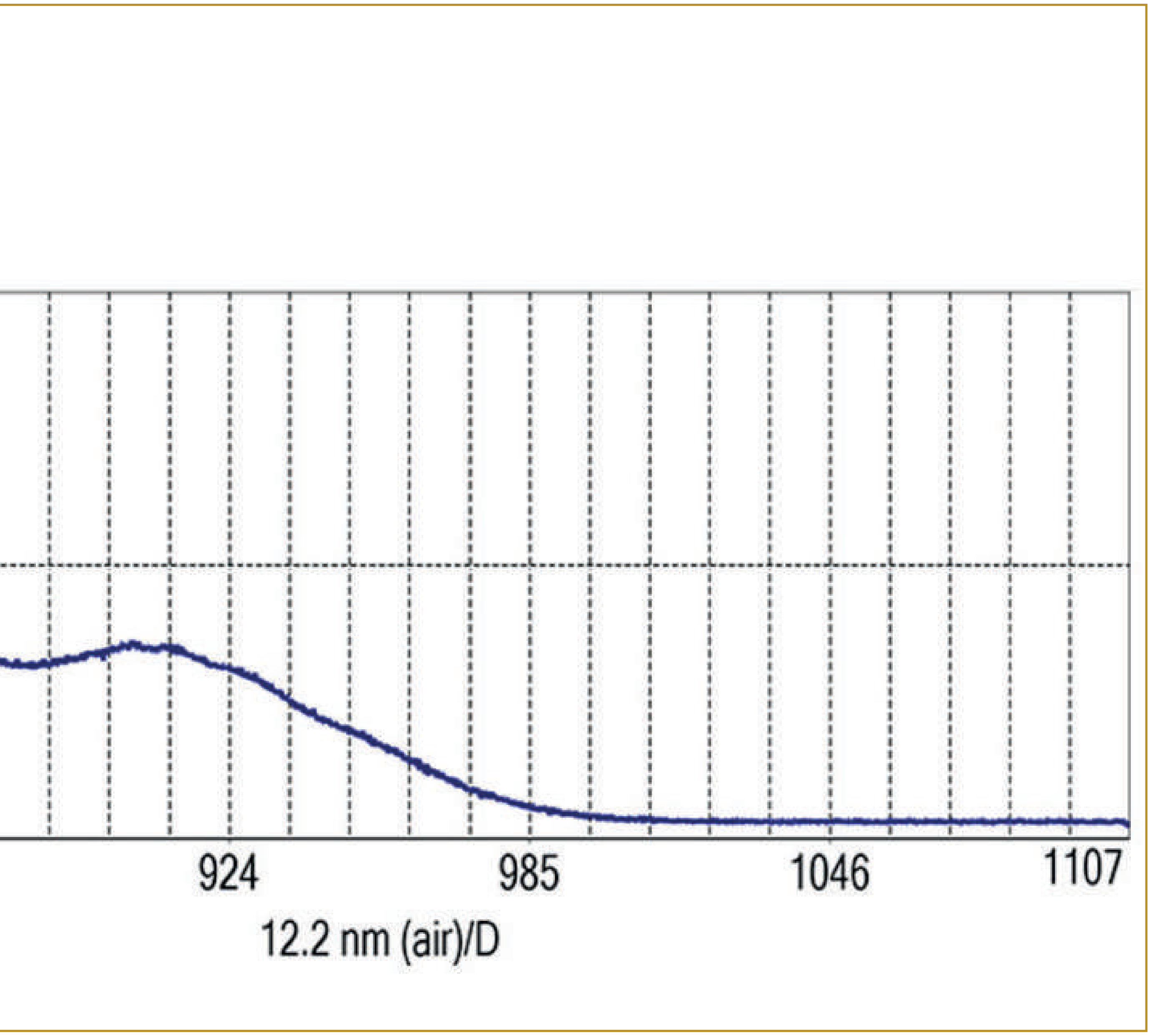


Figure 33: Final PCB footprint



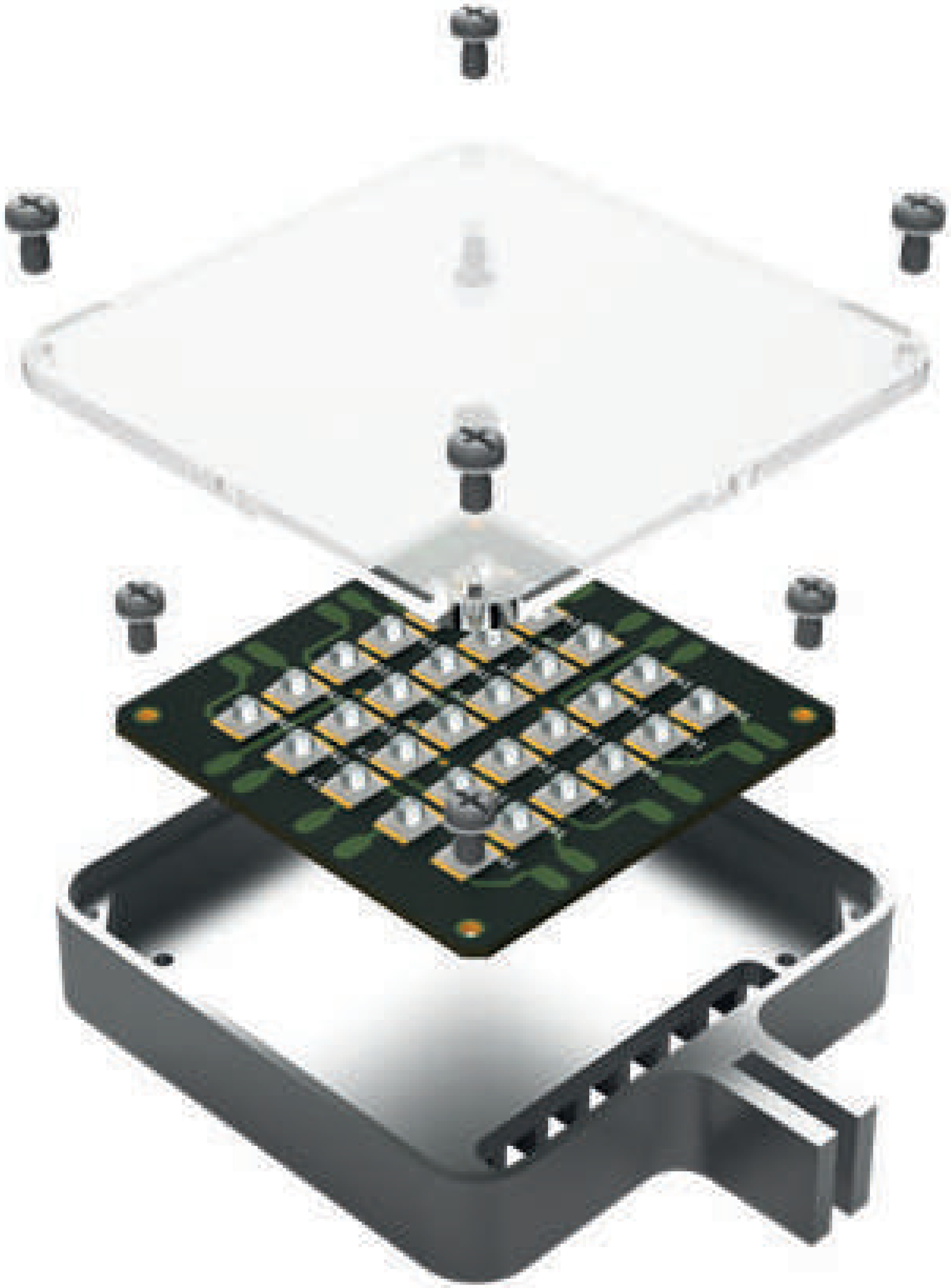


Figure 35: The light case assembly

Finances

The whole budget for the Product Development Project was 10000 euros, from which 5000 euros are allocated to project material expenses and 5000 euros could be spent on travelling to specific project-related locations with project-related purposes. If the entire travel budget is unused, the rest funds could be used on project material expenses.

The expense categories are the following: primary project-related materials (cameras, light, lenses, etc.), other project-related materials (material for presentations and performances), expenses for the manufacturing phase of the project (prototyping, testing), and the last small expense section is Team building.

The range for expense ranges was discussed and implemented in the following way (in percentage format, if the whole amount of expenses increases due to a decrease in the number of travelling expenses):

- 60% - Primary project-related materials (cameras, light, lenses)
- 20% - Manufacturing phase expenses
- 16% - Primary project-related materials (cameras, light, lenses)
- 4% - team building

The travelling budget is planned to be used according to upcoming expenses during group members travelling to appropriate locations. Possible locations to travel for HAREVA Team members are Twente University (Netherlands), the project's headquarters, hospitals with needed technologies and light-providing facilities, and camera and lenses-providing facilities. In the first Research phase of the Project, a small number of expenses were used from the Travelling budget side (less than 50 euros). Moreover, since this project was an Attract project, 5000 euros was also allocated to sponsor the team travelling to Switzerland to visit CERN.

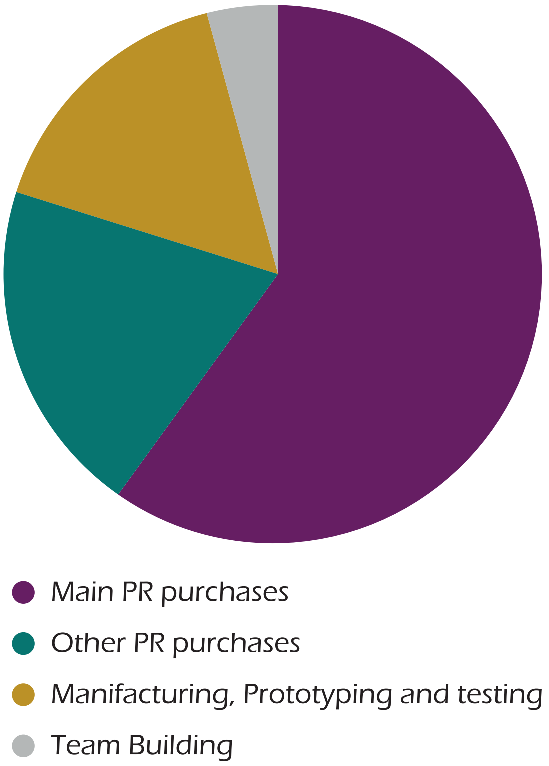


Figure 36: Budget allocation for different purposes

Conclusion

Discussion

At the end of the project, we developed a light source in the NIR spectrum having the most uniform spectrum possible. This light system is one of the main components of the whole surgical headset and was the main challenge of the project. However, we also proposed different locations for the light system to be placed and compared those proposals in terms of feasibility. The final prototype will be sent to our sponsor and used for further development of the H3D-VISIOnAiR project.

Further Developments

Although the light source is now quite significant with 30 LEDs, it is possible to shrink it down with multiband LEDs. For example, USHIO can insert three different wavelengths into one led chip, which means that the footprint of the current design could be only 10 LEDs, i.e. three times smaller. The caveat is that custom LEDs' price rises high unless the order amounts are also considerable, so they aren't suitable for prototyping.

One second potential area for future exploration involves an investigation of the aesthetic qualities of augmented reality images. This avenue of inquiry emerged during ethnographic fieldwork conducted in the hospital setting, as well as in the process of designing graphics for the related project. It became apparent that several challenges must be addressed in relation to the presentation of coloured layers in augmented reality. To overcome these difficulties, a theoretical investigation into practical approaches for highlighting distinct anatomical structures in augmented reality visuals will likely prove necessary. Additionally, a comprehensive examination of the visual preferences of surgeons is warranted. Together, these initiatives could ultimately lead to improvements in the use of augmented reality technology in medical contexts.

Evaluation of our work

The project resulted in creating an infrared lamp with a flat spectrum and a light intensity equal to a halogen lamp, adjustable in intensity and significantly smaller than our Dutch partners have made so far. Our lamp is the only one that can emit that kind of wavelength with that intensity without becoming blistering and being wearable for further tests. Our output is a considerable step forward for the Attract project.
The field research we have carried out will also be crucial in analysing future developments of the Attract technology. Ultimately, the model that connects the lamp to the helmet is also part of the final product. Still, it was crucial iterative research highlighting several critical features to consider when the developers will make the commercial product.

Learning Outcome

Throughout the Product Development Project, we encountered valuable insights regarding different matters. First was the importance of physical prototyping. In this section, we will delve into the significant role of physical prototyping, the importance of knowing the actual operating atmosphere of the product (in our case, the operating room), and other learning outcomes about communication with the customer.

Physical prototyping emerged as a critical step in our project, enabling us to gain a deeper understanding of the surgical headset's design and functionality and set the right location for our light system. By creating physical prototypes, we identified and rectified design flaws, evaluated the ergonomics of the headset, and made informed decisions regarding material selection and component integration. At the beginning of the project, prototyping with available materials helped us to come up with even more ideas. In many stages of the project, we did not have the precise measurements of the model we were trying to construct, which created more challenges for us. However, with the help of trial and error, we could narrow down the possibilities to the actual right ones. Another crucial point we learned about the importance of physical prototyping is the superiority of physical prototyping over software modelling. A notable example would be the "Arc" we modelled and tested in Fusion. The simulated results initially appeared favourable; however, it was only upon the physical 3D printed part that we encountered an unexpected outcome. The printed Arc did not possess the desired stiffness to resist torsion. This experience indeed reinforced the importance of physical prototyping.

As mentioned earlier, in the light system development, our team of engineers and designers had the opportunity to watch actual surgeries. While initially lacking direct experience with operating rooms, hospitals, and surgical procedures, we recognised the importance of immersing ourselves in the real environment where the headset would be utilised. Witnessing the intricacies of surgical procedures, the work-flows, and the interactions between surgeons and their equipment offered us a holistic perspective that could not be adequately conveyed through textbooks or theoretical knowledge alone. One of the most significant benefits of visiting operating rooms was observing the lighting requirements and challenges surgeons face by perceiving the ergonomic considerations involved in surgical procedures. By observing surgeons' movements, postures, and interactions with existing equipment, we gained a deeper understanding of the physical demands placed on them during surgery. This first-hand experience informed the design of the surgical headset, ensuring that it would provide the surgeons' comfort, stability, and ease of use for the surgeons. It must be noted that only the light system was the goal that needed to be achieved, and the headset itself was considered a side product. However, since we decided to also propose a location for the light system, we considered the points mentioned above.

Another important lesson that the whole group has developed is the knowledge exchange. Each step of the way needed someone more familiar with the subject matter to lead the group and share the vision and information to make each individual autonomous in their assigned tasks. There was a great sharing of design methods concerning the research and conception. At the same time, great information and engineering know-how was shared about the prototyping and finalisation part. It was also vital to be in contact with the Design Factory staff to receive constant advice and beneficial teaching.

Another significant learning outcome from our project was the importance of effective communication with our customers. Throughout the initial stages of the project, we encountered numerous questions and sought clarification from our client, an expert in the field. However, we faced challenges in obtaining comprehensive and detailed responses from her. Often, her answers were brief and did not provide the depth of information we required. Despite these communication obstacles, we persevered and continued our efforts to extract the maximum value from her expertise.

In this process, we realised that effective communication with the customer is crucial for the success of any project. It ensures a shared understanding of requirements and expectations and facilitates a collaborative approach toward problem-solving. Although the initial communication hurdles posed challenges, we maintained an open line of communication and adapted our strategies to make the most of our customer's knowledge. By actively listening, seeking clarification, and refining our questions, we were able to navigate the limitations in communication and leverage our customer's expertise effectively. We recognised the importance of persistence and patience in fostering a productive dialogue with the customer, even when faced with difficulties. Through these efforts, we gained valuable insights and refined our design, resulting in a more tailored and impactful final product. This experience emphasised the significance of adaptability and resilience in the face of communication challenges. It reinforced the need to proactively address communication gaps, seek clarification when necessary, and continuously refine our approach to ensure effective collaboration with the surgeons.

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