ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

MECHANICAL ENGINEERING PROJECT I

ME-401

Design and development of a display device for Lippmann plates

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1 Introduction

1.1 About Lippmann and plates

In 1908 the french scientist Gabriel Lippmann won the Nobel prize in physics "for his method of reproducing colours photographically based on the phenomenon of interference" [1]. The Lippmann method is a two-way method that makes it possible to make colour images directly through the wavelength of the light reflected from the object that is captured [2]. This was the first method developed to produce colour images that record the entire spectrum of light. This is made possible by covering a glass plate with an extremely fine grain emulsion. By placing a reflective surface of mercury mirror on top of the emulsion it is then possible to capture the image using standard camera optics [1]. With this technique the interference pattern is stored in the emulsion and therefore also the spectrum of the light captured [3].

1.2 Musée de l'Elysée

Musée de l'Elysée in Lausanne, today have a unique series of 133 landscapes, portraits and still lifes colour photographs made by Lippmann himself [4]. Today these are not exhibited, but they are planning to have an exhibition in 2021, exactly 100 years after the death of Gabriel Lippmann.

1.3 Why display device is necessary

To be able to see the whole colour spectre of the motive on the Lippmann plate the light should come from a diffuse light source containing a full range of wavelengths in the visible spectrum. Secondly the angle of illumination have to be right to be able to see the colours in the image. In order to do this the viewing angle has to be the mirrored angle of the illumination angle. To remove the surface reflection that interferes with the reflection from the inside of the plate, the plates are mounted under a prism. Because the light is reflected from the top of the prism as well as the plate it is necessary to make sure only the right reflection is shown, namely the one from the plate. This is illustrated in Figure 1. Here the yellow line represents the light emitted from a light source in the left side of the picture. The yellow line is also what the viewer on the right side wish to observe. The red line on the other hand is the reflection of the light source on the prism. It is important that those two lines does not intersect at the point of the viewer so that the reflection from the prism will disturb the image.

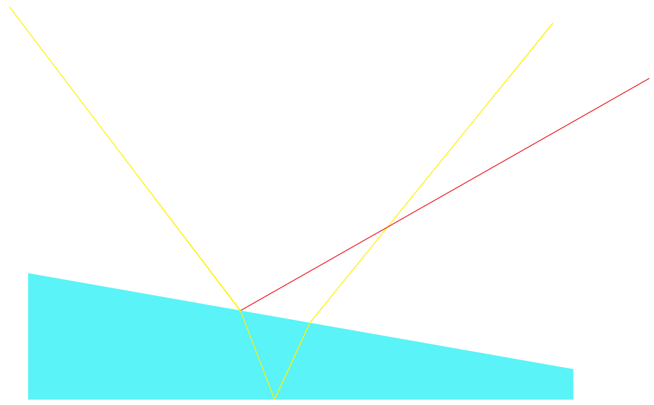


Figure 1: Representation of desired and undesired reflection.

By changing the angle of illumination, the different parts of the colour spectrum in the image can be observed. This can normally be obtained by tilting the plate, but because the original Lippmann plates are irreplaceable the visitors can't be allowed to hold the plate them self. Therefore a device that let the visitor change the angle of illumination, without actually holding the plate, is necessary in order to see this effect. In Figure 2 the colour shift is shown for a picture produced with the Lippmann technique for eight different angles. The picture where the angle of illumination is 0, is the one where the colours of the motive are represented most accurately.

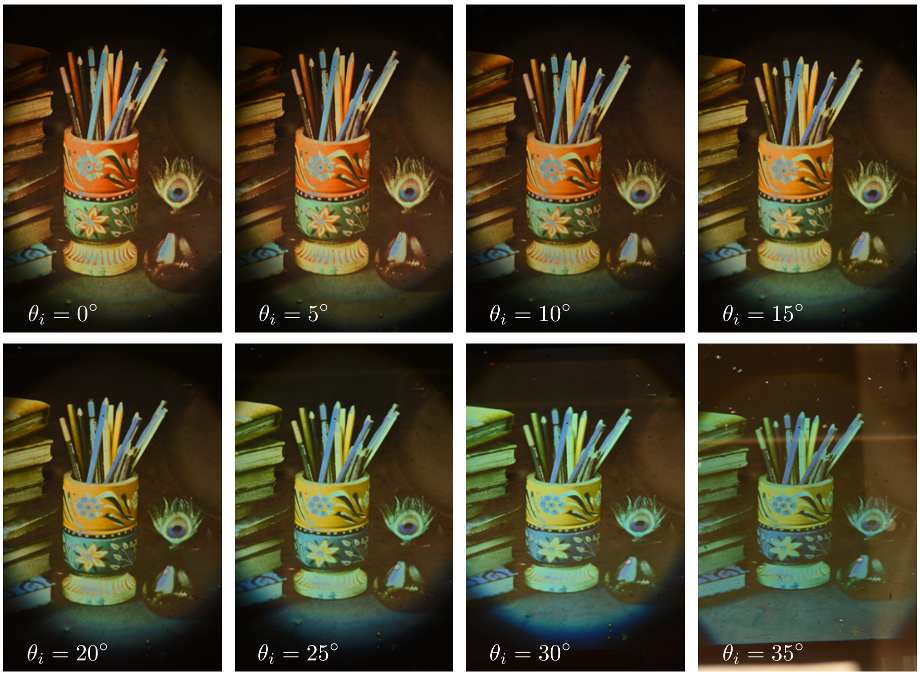


Figure 2: Photography produced with the Lippmann technique in the Audiovisual Communications Laboratory at EPFL, illuminated at different angles. [5]

2 Initial requirements

In order to develop a suitable product it is necessary to first establish a list of requirements and constraints for the project. A meeting with the end user, Musée de l'Elysée, was not possible to arrange in the initial phase of the project. Therefore a list of requirements and constraints is established on the basis of the supervisors earlier contact with the museum and a number of assumptions.

- Physical size of display case:
  The device has to be small enough to fit inside the existing display cases that Musée de l'Elysée possess today. Because it has not been possible to measure those, the design has to be as compact as possible in order to make sure it will fit.
- Controlled environment:
  Since the plates are originals and therefore of great value, both historically and economically, it is important that the degradation of the plates is as little as possible during the exposition. That is why they will be displayed in a controlled environment inside the case where the humidity and temperature can be adjusted to the optimal conditions.
- Power source:
  Both the display device and the light source requires a power source to operate. The installation of the device should be as simple as possible, therefore it has to come whit a standard socket power supply.
- Wiring:
  It is necessary to have wires running from the display device, out of the case and to the controller unit hidden under the case. Wires will also run from the controller to the unit operated by the visitors.
- Users:
  The device has to be easy and intuitive to operate for visitors of different age groups. It must also be possible to use regardless of height of the person. The ultimate goal is that the user is able to play effortlessly with the angle of the plate and see how the different positions affect the colours.
- Aesthetics and simplicity:
  The device must be compelling to look at, and at the same time simple and minimalist. This is important because the art should have the full attention of the visitor.
- Adaptability:
  Because the plates are produced in a number of different sizes the tilting device should support multiple sizes of plates. It should also be easy to change between the different plate sizes.

3 Meeting with museum

After the construction of the first two prototypes a meeting with the museum was arranged. Most of the initial requirements and constraints were confirmed and some new ones were added:

- The part of the device that is in contact with the plate must be of a chemical inert material. This is to prevent the device from accelerating the degradation of the plates

- The temperature in the display case must be 20°C and have a humidity of 40%.
- It is not acceptable if the motor emits so much heat so that it heats up the plate or the closed environment inside the display case.
- Plates should be fixed on all sides. The risk of the plate sliding of the device has to be zero.
- The user interaction should be kept simple and minimalist.

4 Design and prototypes

In order to change the angle of illumination without touching the plates, different options were available. First option was a situation where the plate was stationary, with a dynamic light source. The light source would then need to move vertically while simultaneously changing angles in order to change the illumination angle while targeting the plate. This option would minimise interaction with the plate itself, but would require a larger and more complex light installation on the wall. The second option, the option that was chosen to develop, was a situation where the light source is stationary, while the plate is able to tilt. This would require a small tilting platform under the plate. Electronic motors and controls would then tilt the plate while keeping it in a controlled environment. The first designs were based on tilting the Lippmann plate towards the observer, with a stationary light source on a wall behind the platform. By tilting the plate towards the observer the illumination angle would change accordingly to the degree of tilt. One problem with this solution was that the observer would have to move in order to obtain all the angles of illumination to see the full spectre of the image, another was that the reflection of the prism itself would also change and come into the observers field of vision. In the last design these problems was addressed by instead of tilting the plate towards the user, the plate would tilt sideways, accompanied with an arc of light over the platform. The observer would then be able to observe the spectrum shift effect that is a particularity of Lippmann plates. This solution locks the desired viewing angle, but also locks the angle of the undesired angle of prism reflection. The observer can then stay in the same position as the platform tilts, and the curved light will be able to hit the plate through the entire motion.

In total 5 different designs have been made on basis of the constraints. The first 4 designs were based on the platform tilting towards the user, while the fifth and final design tilts sideways. They were all designed using Solidworks CAD software. Also 4 different prototypes were constructed through the development. Rapid prototyping gives the opportunity to test and verify designs rapidly through the design process. The prototypes are not meant to represent the quality of the final product, but serve as testing platforms and visual aid for further development.

4.1 2-way tilt

4.1.1 Design

The two way tilt shown in Figure 3 was designed in order to make it possible for the user to play with the plate just as if he was holding it. Two servo motors would make it possible to tilt the plate in two axis.

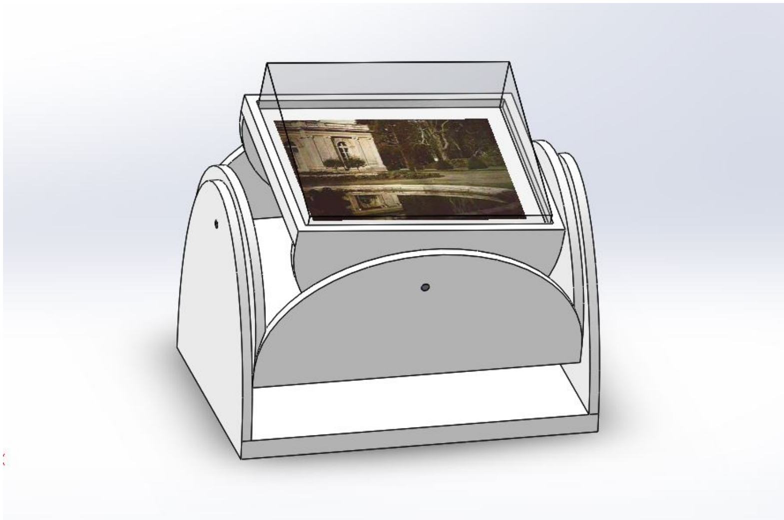


Figure 3: 2-way tilt CAD model

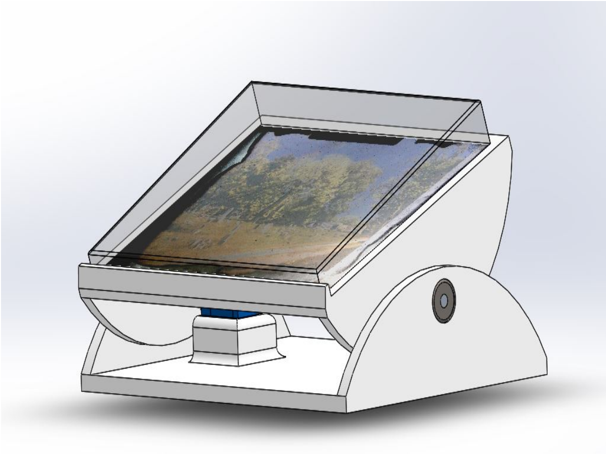
4.1.2 Prototype

Since a two way tilt is not necessary in order to see the whole colour spectrum, and unnecessarily complex, it was decided to not go any further with this concept. No prototype was therefore constructed.

4.2 One-way tilt

4.2.1 Design

The one-way tilt device was designed in order to be as simplistic and minimalist as possible with a simple tilting platform driven by a single servo motor by direct transmission. Figure 4 a) shows the CAD model of the device with a large Lippmann plate covered by a prism, in b) the exploded view of the device can be seen.


(a) Assembled view.

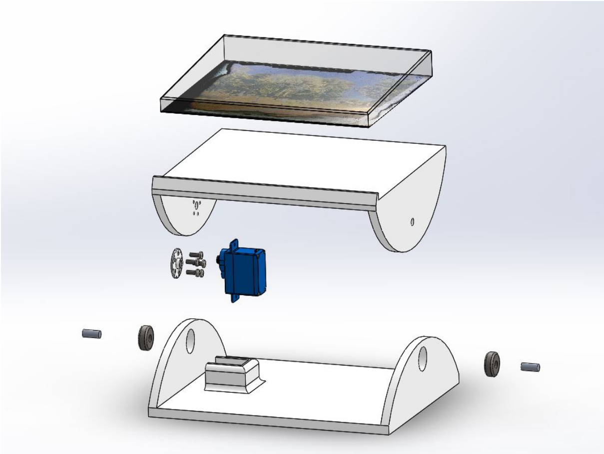

(b) Exploded view.

Figure 4: One-way tilt CAD model.

4.2.2 Prototype

Design number 2 was constructed on basis of the CAD model. This was done extracting machine drawings from Solidworks and then constructing the parts by using wood and wood cutting tools. Finally the parts were assembled using epoxy. Figure 5 shows the final prototype. This prototype have multiple problems. First of all the plates are not fixed. They are only supported in the lower part. This means that there is a risk of the plate sliding of if the loop is running for a sufficient amount of time. Secondly the prototype will take quite a bit of the attention since it is always very visible. Especially for the small plates a large part of the top plane will be exposed. This is not ecstatically satisfying.

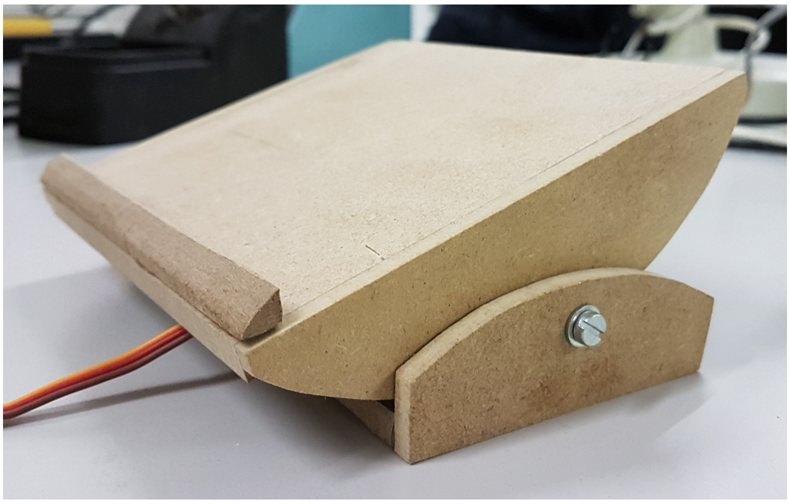
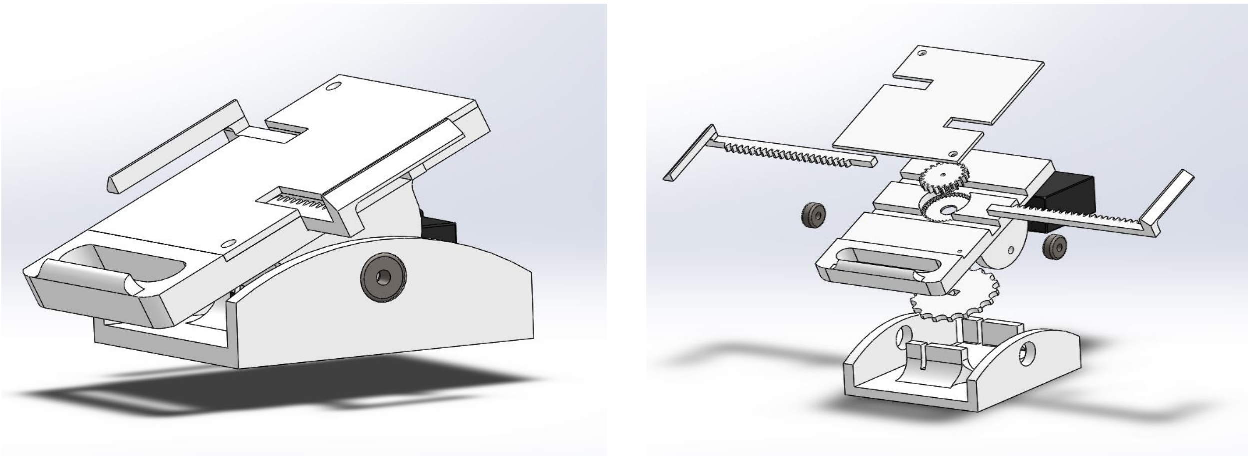


Figure 5: One-way tilt prototype.

4.3 One-way tilt with size adjustments

4.3.1 Design

Feedback on the first prototype made it obvious that a more secure fixation was necessary. Also a less visible device, especially when displaying the small plates was preferable. Therefore a device with size adjustments was constructed. This meant a considerably more advanced design, but on the other hand both the aesthetically, and fixation constraints would be satisfied with this concept. In Figure 6 the assembled and exploded view of this design is shown.



(a) Assembled view. (b) Exploded view.

Figure 6: One-way tilt with size adjustments.

4.3.2 Prototype

The parts for the design number 3 were produced in PLA by 3D-printing using a "Prusa i3 MK2" 3D-printer. The assembly was done using screws and epoxy. This prototype is more minimalist as it is just the support bars that will be visible regardless of the size of the plates. The problem with this design is first and foremost that the support does not gives satisfactory fixation of the plates. Secondly the complexity makes it hard to manufature. The prototype is shown in Figure 7.

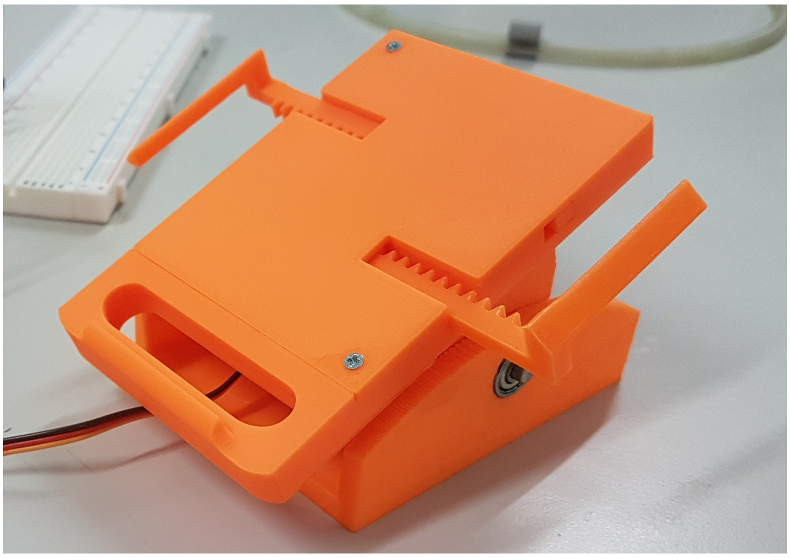
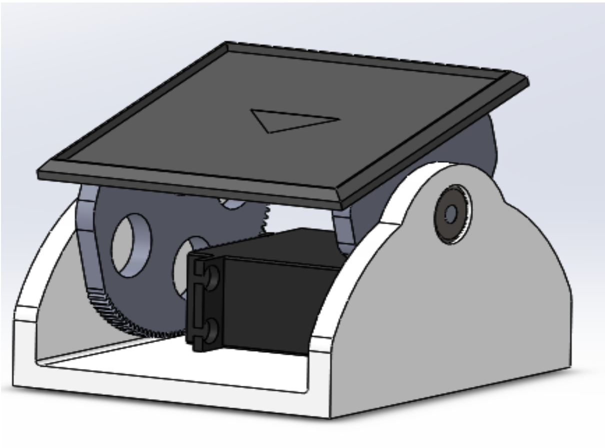


Figure 7: One-way tilt with size adjustments.

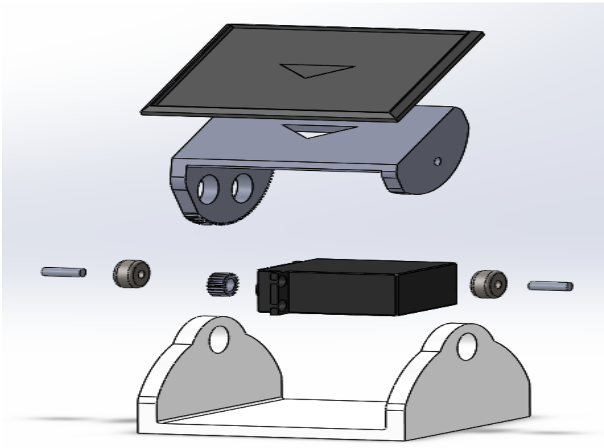
4.4 One-way tilt with interchangeable plate mounts

4.4.1 Design

The fourth design focused on a less complex design, and better fixation. In stead of adjustable fixation, an interchangeable mounting plate was implemented. This makes it possible to create mounting plates that fits perfectly to different size of plates, while keeping the tilting platform small. A gearing ratio of 7:1 was also implemented in order to make the tilting motion smother. The new design can be seen in Figure 8.



(a) Assembled view.



(b) Exploded view.

Figure 8: One-way tilt with interchangeable top mounts.

4.4.2 Prototype

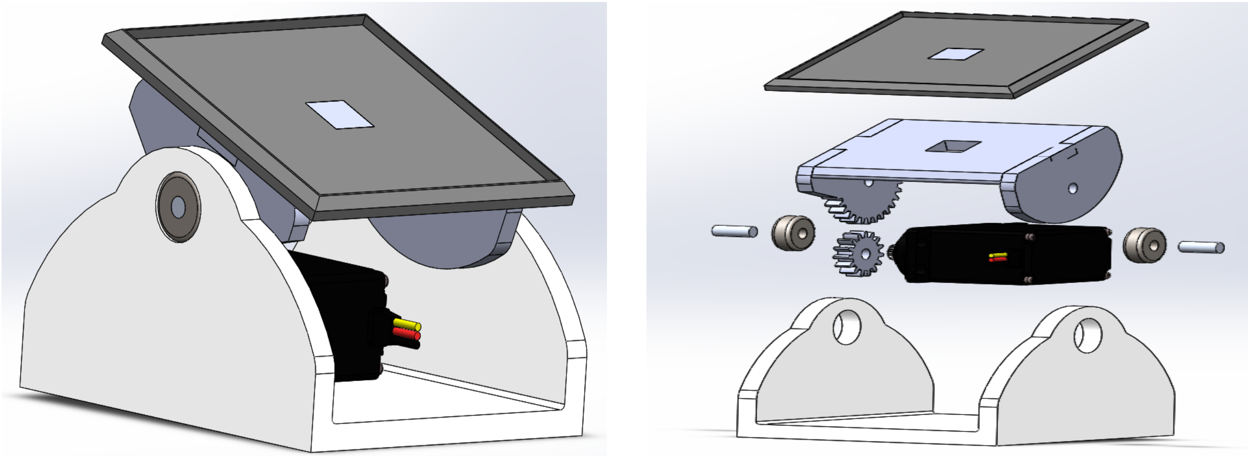
The parts for this design were also 3D-printed in PLA as seen if Figure 9. Assembly was done using using epoxy and press fitting. This design makes it possible to have a satisfactorily fixation of plates of any size since an unique top mount can be custom made for each and every plate. With the implemented gearing the tilting motion became significantly smother.

Figure 9: One-way tilt with interchangeable top plates.

4.5 One-way tilt with interchangeable plate mounts and large range of tilt

4.5.1 Design

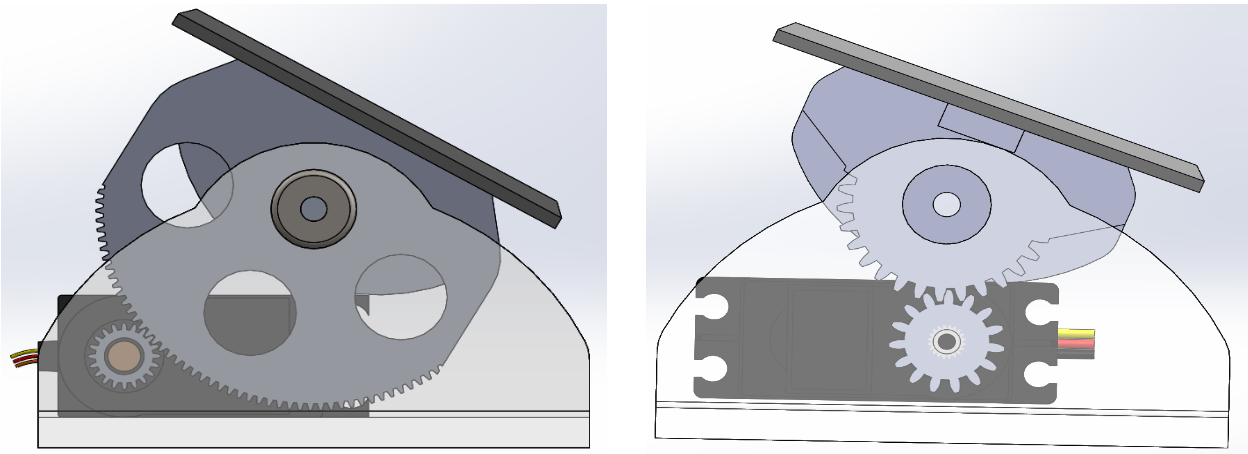
The last design is highly based on the previous one, as can be seen in Figure 10, but had to be able to tilt sideways with a much larger range of angle. Since this concept required a larger tilting angle, 45° in both direction, the gear ratio had to be changed from a 7:1 ratio to a 2:1 ratio. This affects the smoothness of the tilt, but gives an larger range of tilt. The mounting plate was also redesigned in order to make rotating of the top mount possible.



(a) Assembled view. (b) Exploded view.

Figure 10: One-way tilt with interchangeable top mounts large range of tilt.

In Figure 11 the design with small range of tilt, a), is compared with the new design with a large range, b). Because the servo used for the prototype only have a 180° range of movement, the gear ratio had to be adjusted in order to make a 90° tilt possible. The gear ratio in the design with large range of tilt is therefore 2:1, instead of 7:1 as used for the design with small range of tilt. The drawback with this is that the movement of the tilt is less smooth in the large range tilt design.



(a) High gear ratio, 30° tilt. (b) Low gear ratio, 90° tilt.

Figure 11: Difference between high and low gear ratio.

4.5.2 Prototype

The last prototype was created by changing out the gear and mounting plate mechanism on the previous prototype.

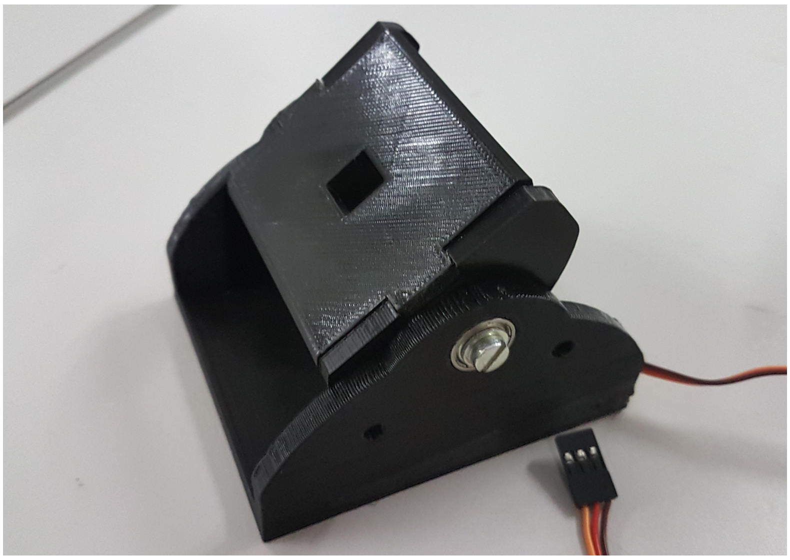
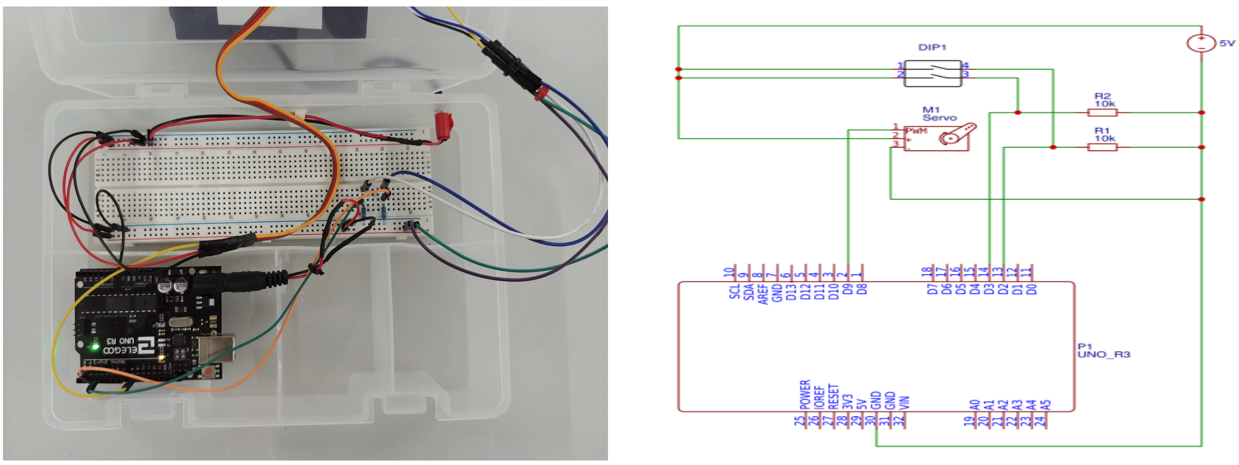


Figure 12: One-way tilt with interchangeable top plates and large range of tilt.

5 Electronics

In Figure 13 a) a picture of the electronics in the final prototype is shown, while in b) the schematic of the electronics is given. The electronics consists of the following:

- Arduino Uno R3 board
- Mountain ark high torque servo
- 3-position rocker switch
- 5v power supply
- 2x 10$k\Omega$ resistance



(a) Electronics prototype.

(b) Schematic of the electronics.

Figure 13: Electronics.

6 Software

The software for the tilting device is written in Arudino programming language. This is a simple and open-source platform something that makes it easy for later updates or changes of the code in the future if that is necessary [6]. Multiple different ways of controlling and interacting with the tilting device were investigated. Finally code was written for two different solutions of controlling the tilt. Namely the use of a joystick or the press of a button. For each one of these hardware solutions, different types of code were developed.

1. Joystick:
   The joystick allows the user to control the tilt of the plate by controlling the joystick. When the user let go of the joystick the plate will stay stationary for a given amount of time, in its current position, in order for the user to enjoy the picture with illumination in the given angle. When no one is interacting with the device the plate will run a continuous loop between the two end positions. The code is implemented so that the user can take control of the movement any where in the loop.
2. Button:
   The button can be implemented in multiple ways. Therefore different types of code were developed for this.
   (a) First approach is that the device runs a continuous loop when no input is given, and then stops the movement when the button is pushed. That way the user can hold the button for as long as desired in order to enjoy the picture in the given angle. The drawback with this solution is that the device will constantly run the loop, even when nobody is watching. This gives an increased tear and wear on the device and the servo motor will constantly consume electricity.
   (b) The other approach is to let the device have an initial, stationary position when nobody is interacting with the unit. Then when the button is pushed the device starts the loop and keep on running until the user releases the button. Finally when the button is released the plate will stay in that given angle for a given amount of time, before returning to the initial position. The button can be pressed again at any time to continue the loop. The upside with this approach is that the electricity consumption and tear and wear of the device will be greatly reduced. On the other hand the user have to wait for the loop to get into the desired position.
   (c) The last approach is a two-way flip button, something that allows the tilt to be controlled both ways at any given time. The plate is still stationary in the initial position whenever the button is unpressed. With this approach the user can control the device to any desired tilt at any time, without waiting for the loop to run.

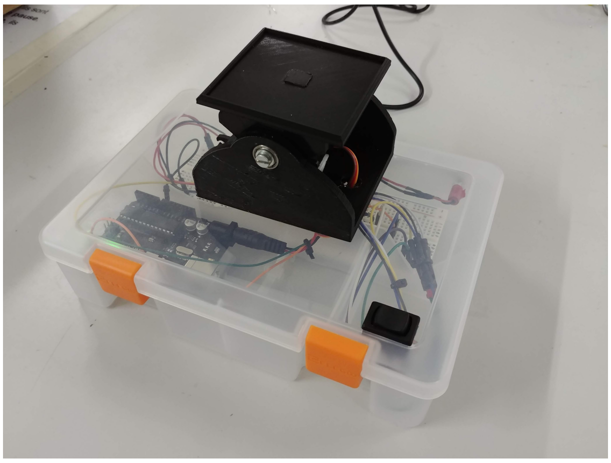
The approach with the button implemented in the way described in point c) was in the end selected for the finally prototype. It was multiple reasons why this was the desired implementation. First of all it is crucial that the device is easy and intuitive to use. With this approach it should be possible for users of all ages to easily take use of the device. Finally this approach lets the device be stationary when not in use. This is preferable from a power consumption perspective, but also in terms of longevity of the device. It also makes it possible to set an initial position where the viewing angle is desirable.

7 Final prototype

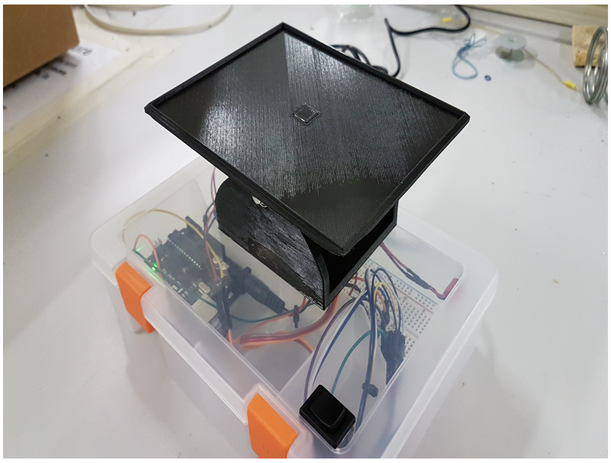
In Figure 14 the CAD model of the final tilting device is shown with a Lippmann plate under a prism.

Figure 14: Design of final prototype.

The final prototype of the tilting device is mounted on top of a box containing all the electronics and the switch to control the tilt. The device can be seen in Figure 15 with a top mount for a small Lippmann plate in (a), and large one on in (b).



(a) Small plate



(b) Large plate.

Figure 15: Final prototype.

8 Display case

As discussed in the introduction, it is important to make sure that the reflection of the prism does not interfere with the reflection of the plate itself. The light source should ideally be placed more or less perpendicular to the plate, but since it than would be necessary for the observer to be positioned at the exact same spot as the light source, this is not possible. Therefore the light source is shifted slightly backwards in reference to the plate. Still the undesired reflection from the prism have to be avoided. This is way it is necessary with a fairly large distance from the plate to the light source. Finally the 190° light source makes it possible for the observer to see the colour shift as the angle of reflection changes as the plate tilts. The following two subsections contains the design of the display case both for a single plate intended for use at EPFL, and a larger case for displaying multiple plates at the same time.

8.1 Display case for EPFL

The display case designed for use at EPFL is designed for displaying one plate at the time only. From Figure 16 the display case is shown with the tilting device with a small plate on display. Because this is going to be used at EPFL, and the plates displayed will not be original Lippmann plates, a closed box is not necessary.

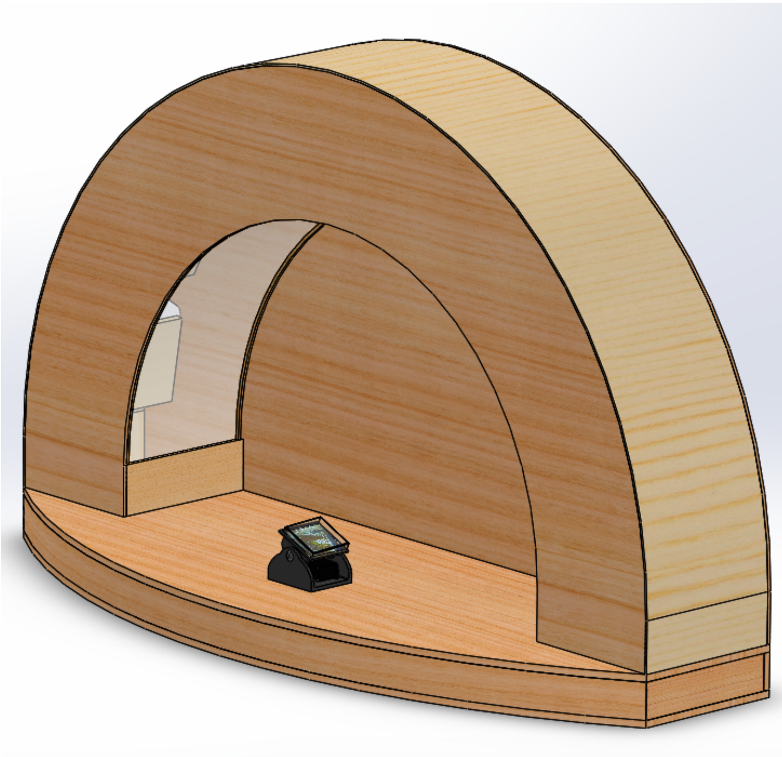


Figure 16: Display case with tilting device, front.

In Figure 17 the back of the display case can be seen. The circular pattern of holes in the back plate are intended to provide air circulation to the spots inside the case to prevent overheating. In the bottom of the plate there is a slot for power cables.

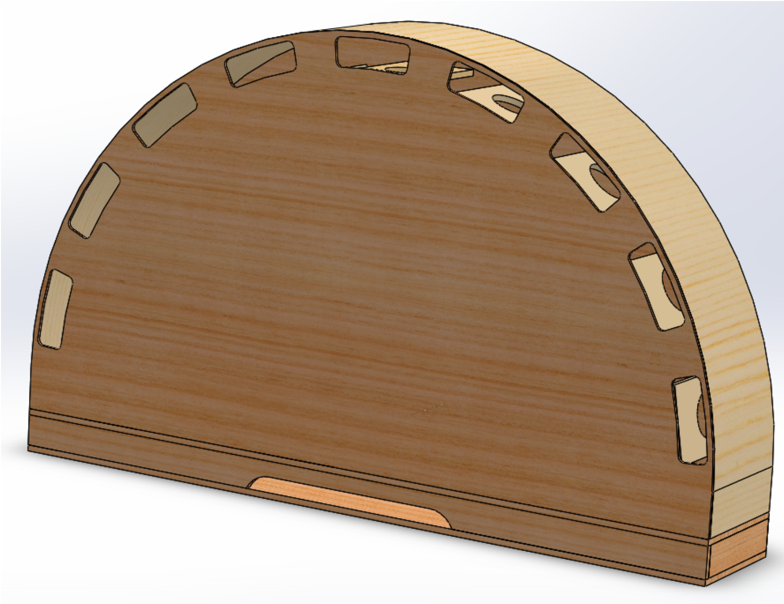


Figure 17: Display case, back.

In Figure 18 the cross section of the display case can be seen. The arc is designed to hold 9 spots and a diffuser plate in order to have an even and diffuse illumination of the plate from every angle .

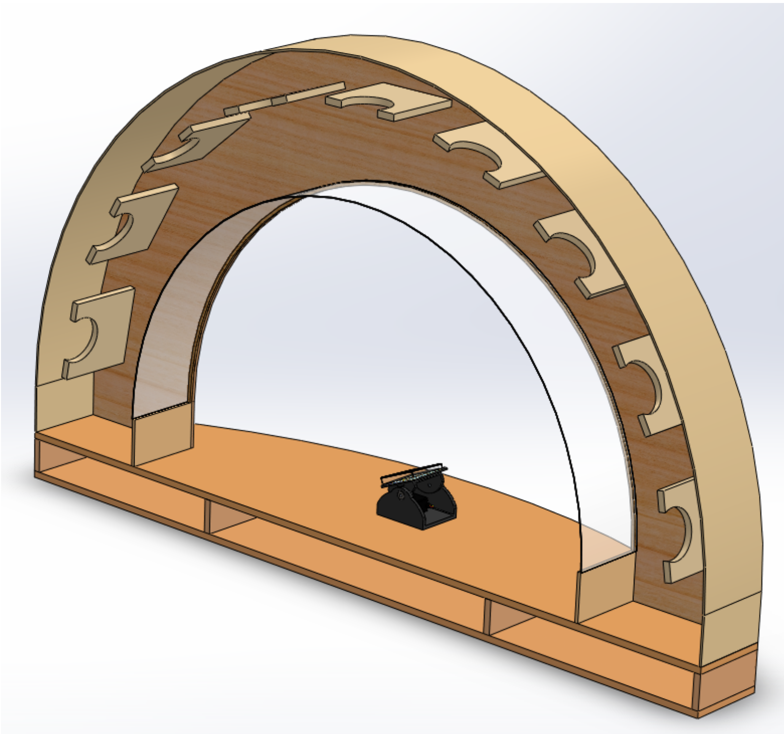


Figure 18: Display case with tilting device, cross section view.

8.2 Display case for Musée de l'Elysée

Since displaying a single Lippmann plate in a large display case is highly space consuming, a wall mounted lighting fixture was designed for use in Musée de l'Elysée. This design will be mounted above a display monter containing several Lippmann plates. It is based on the same principles as the display case for EPFL with a curved light source. Figure 19 and Figure 20 shows how this concept would look and how it could be mounted above a display monter. This lighting fixture can be produced to any width to accommodate the size of the display monter.

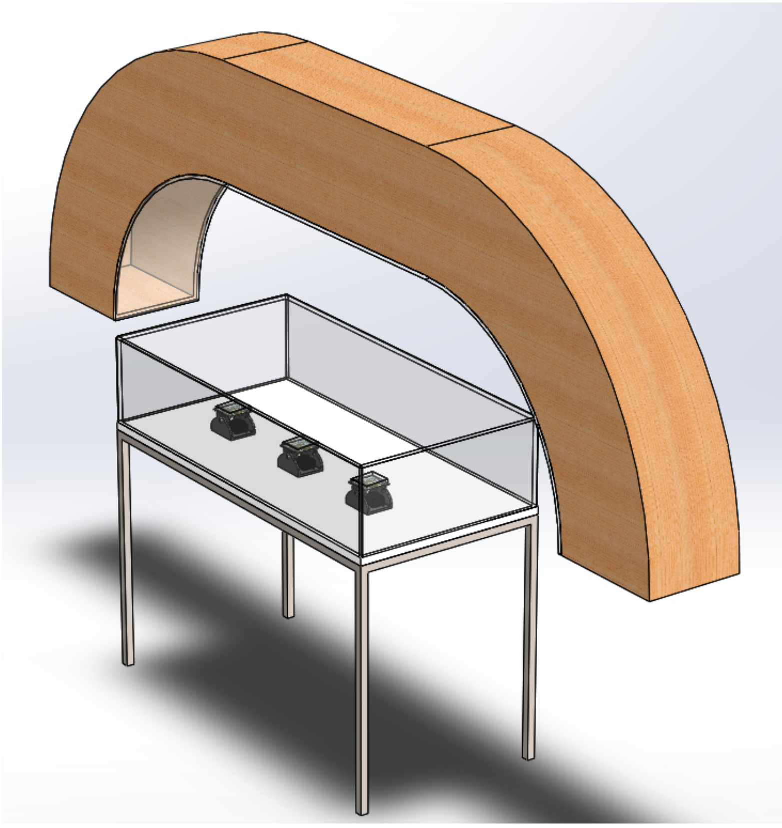


Figure 19: Wall mounted lighting fixture.

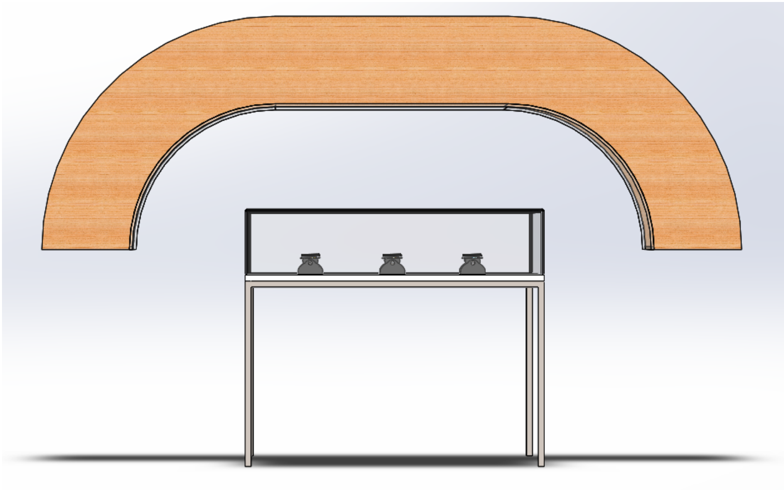


Figure 20: Wall mounted lighting fixture.

9 Reflection and future development

Because of uncertainty in requirements through the major part of the project, the focus has been on designing and testing several concepts which could be used. For every iteration, the design and requirements has adapted towards a final concept. The designs has been both very simple, and very complex, and ended up with a balance of both. Each new design builds on the experience gained from the last. Further development should take use of this experience and focus on improvement and production.

The following improvements are suggested:

- A more suitable production method should be selected: This will allow for an increased amount of freedom in terms of the materials selected. In order to increase the lifespan of the device, at least the mechanical gears should be made from a stronger, more durable material.
- The movement of the tilting plate should be more even: This can be obtained in multiple ways. One possible solution is to use a stepper motor instead of a servo motor. The range of motion is not limited on a stepper motor, something that allows for a gear system with a larger reduction while maintaining the desired 90° of tilt. This will make it possible to achieve a very controlled tilt.

References

[1] *Nobel prize homepage*. URL: https://www.nobelprize.org/nobel_prizes/themes/physics/biedermann/index.html.
[2] *Sur la théorie de la photographie des couleurs simples et composées par la méthode interférentielle*. URL: https://hal.archives-ouvertes.fr/jpa-00239844/document.
[3] *Lippmann EPFL*. URL: https://lcav.epfl.ch/page-152296-en.html.
[4] *Musée de l'Elysée*. URL: http://www.elysee.ch/en/collections-and-library/the-collections/photographers/.
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